Making Sense of the Debate about Hatchery Impacts

Interactions Between Enhanced and Wild Salmon on Canada's Pacific Coast

Prepared for the Pacific Fisheries Resource Conservation Council by

Julia Gardner, David L. Peterson,
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March 2004

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TABLE OF CONTENTS

EXECUTIVE SUMMARY 8
Context for enhancement 8
Enhancement methods 8
Other key factors 8
Interactions of enhancement and wild salmon 10
Knowledge base 10
Guiding principles 11

1. DELVING INTO A CONTENTIOUS SUBJECT 12
1.1 Aiming to clarify conflicting views on enhancement 12
1.2 Why is the focus of enhancement on salmon? 12
1.3 The essence of the debate 13
If we are producing more salmon, why aren't there more salmon in the ocean? 13
Hatcheries are only one of many pressures on wild salmon 15
Ocean and climatic conditions have effects that are difficult to distinguish from the impacts of enhancement. 16
Hatcheries are only one of several approaches to enhancement 16
Many questions arise around the nature of interactions between enhanced and wild salmon. 16
1.4 Targeting enhancement effects on wild salmon in B.C. and Yukon 16
1.5 Overview of approach and contents 17
1.5.1 Approach 17
1.5.2 Information constraints 18
1.5.3 Organization of the report 18

2. THE NATURE OF SALMON 19
2.1 The seven species of salmon 19
2.2 The life cycle of the salmon 19
2.3 Production and productivity 22

3. ORIGINS AND EVOLUTION OF ENHANCEMENT 23
3.1 The roots of enhancement in North America 23
3.2 Enhancement in British Columbia prior to the Salmonid Enhancement Program (SEP) 23
3.3 The evolution of the Salmonid Enhancement Program 24
3.3.1 The early years 24
3.3.2 Juvenile salmon releases from enhancement in B.C. over the past half century 26
3.3.3 Evaluations of SEP 27
3.3.4 Reorganization of SEP into HEB 27
3.3.5 1998-2003: An Ongoing Series of Changes 28
3.4 Federal and provincial enhancement in B.C. and Yukon today 28
3.4.1 Enhancement programs in B.C. and Yukon 28
3.4.2 Province of British Columbia programs 29
3.4.3 SEP releases since 1978 30
3.5 Emerging problems with enhancement from experience in the North Pacific 33

4. FACTORS AFFECTING INTERACTION BETWEEN ENHANCED AND WILD SALMON 35
4.1 The purposes of enhancement 35
4.2 The differences between natural and hatchery habitat 36
4.2.1 Adaptation to natural environments 36
4.2.2 Salmon homing and straying 36
4.2.3 Hatchery salmon 37
4.3 Survival rates by life stage 37
4.4 When and where interactions occur 38
4.5 Technologies and practices 38
4.6 Scale of production of salmon from enhancement relative to wild stock abundance 39

5. TRENDS IN ENHANCED SALMON PRODUCTION RELATIVE TO WILD SALMON PRODUCTION 42
5.1 Contribution of enhancement to production 42
5.2 Possible scenarios of relative production 44
Possible scenarios if total abundance is declining 44
Possible scenarios if total abundance is staying the same or increasing 45
5.3 Distinguishing ocean effects from impacts of enhancement on wild salmon 45

6. ENHANCEMENT METHODS 47
6.1 Increased access to natural habitat – Obstruction removal 48
6.1.1 The technology and how it works 48
6.1.2 Location of enhancements 49
6.1.3 Associated survival rates 50
6.1.4 Overview of obstruction removal and its effects 50
6.2 Improved or restored natural habitat 50
6.2.1 The technology and how it works: Habitat restoration 50
6.2.2 The technology and how it works: Temperature and flow control 51
6.2.3 Number, size and location of enhancements 51
6.2.4 Associated survival rates 52
6.2.5 Overview of habitat restoration and its effects 52
6.2.6 Overview of controlled flow and temperature and their effects 53
6.3 Lake and stream enrichment 53
6.3.1 The technology and how it works 53
6.3.2 Number, size and location of enhancements 54
6.3.3 Associated survival rates 55
6.3.4 Overview of lake enrichment and its effects 56
6.3.5 Overview of stream enrichment and its effects 56
6.4 Artificial habitat with natural spawning and rearing – Channels 57
6.4.1 The technology and how it works 57
6.4.2 Number, size and location of enhancements 57
6.4.3 Associated survival rates 58
6.4.4 Overview of spawning channels and their effects 58
6.4.5 Overview of rearing channels and ponds and their effects 58
6.5 Human controlled spawning, or human controlled rearing 59
6.5.1 Human controlled spawning – Incubation 59
6.5.2 Human controlled rearing – Feeding 59
6.6 Human controlled spawning and rearing combined – Hatcheries 60

6.6.1 The technology and how it works 60
6.6.2 Number, size and location of enhancements 61
6.6.3 Associated survival rates 62
6.6.4 Overview of hatcheries and their effects 63
6.7 Species focus of various enhancement methods 63

7. INTERACTIONS BETWEEN ENHANCED AND WILD SALMON 65
7.1 Mixed stock fisheries interactions 65
7.1.1 Possible negative effects 65
7.1.2 Counter-arguments and/or possible positive effects 67
7.1.3 Experience and examples 68
7.2 Genetic interactions 74
7.2.1 Possible negative effects 74
7.2.2 Counter-arguments and/or possible positive effects 77
7.2.3 Experience and examples 78
7.3 Competition 79
7.3.1 Interrelationship of competition and predation 79
7.3.2 Possible negative effects of competition 80
7.3.3 Counter-arguments and/or possible positive effects 81
7.3.4 Experience and examples 82
7.4 Predation 83
7.4.1 Possible negative effects 83
7.4.2 Counter-arguments and/or possible positive effects 83
7.4.3 Experience and examples 84
7.5 Fish health 85
7.5.1 Possible negative effects 85
7.5.2 Counter-arguments and/or possible positive effects 86
7.5.3 Experience and examples 86
7.6 Habitat degradation 87
7.6.1 Possible negative effects 87
7.6.2 Counter arguments and/or possible positive effects 87
7.6.3 Experience and examples 87

8. PROTECTING WILD SALMON: ASSESSMENT, MITIGATION AND REFORM 88
8.1 Assessing enhancement 88
8.1.1 Information needed for effective assessment of enhancement 88
8.1.2 Overview of assessment methods and programs 88
8.1.3 Adequacy of and capacity for assessment 93
8.2 Mitigative measures to reduce negative interactions 94
8.3 Hatchery reforms dealing with wild stock interactions 98
8.4 Recent developments relevant to the future of enhancement 102
8.4.1 Recent legislation 102
8.4.2 DFO policies released in 1998-2000 103
8.4.3 Pacific Fisheries Adjustment and Restructuring Plan (PFAR) 103
8.4.4 Funding cutbacks 104

9. THE STATE OF THE KNOWLEDGE BASE 109
9.1 General research challenges 109
9.1.1 Research challenge: Experimental design 109
9.1.2 Research challenge: Lack of basic information and data 110

9.1.3 Research challenge: Difficulties in defining stocks and populations 110

9.2 Knowledge gaps and research challenges regarding interactions between enhancement and wild salmon 111

9.2.1 Knowledge gaps: Mixed stock fishery interactions 111

9.2.2 Knowledge gaps: Genetic interactions 111

9.2.3 Knowledge gaps: Competition and predation interactions 112

9.2.4 Knowledge gaps: Fish health interactions 113

9.3 Information to put enhancement in context 114

10. CONCLUSIONS AND GUIDING PRINCIPLES: THE IMPACTS OF ENHANCEMENT ON WILD SALMON 115

10.1 Relative impacts from different methods of enhancement 115

10.1.1 Key interactions with wild salmon related to habitat enhancement (increased access through obstruction removal, restoration or lake/stream enrichment) 115

10.1.2 Key interactions with wild salmon related to channels and ponds (artificial habitat with natural spawning and rearing) 116

10.1.3 Key interactions with wild salmon related to hatcheries (human controlled spawning and rearing) 118

10.2 Overview of estimated impacts of enhancement on wild salmon 119

10.2.1 Summary of risks to wild salmon from enhancement and the key factors involved 119

10.2.2 Benefits of enhancement to wild salmon 123

10.2.3 Putting enhancement into a broader and long-term context 124

10.3 Guiding principles 125

10.3.1 Operate hatcheries and enhancement facilities with primary regard for their potential impacts on wild salmon 125

10.3.2 Treat enhancement projects like experiments; learn from the results; and change practices to minimize impacts on wild salmon based on the lessons learned 126

10.3.3 Undertake research, monitoring and assessment to provide a solid foundation for evaluation of enhancement and adaptive management 126

10.3.4 Use a combination of enhancement and management strategies to protect wild salmon, focusing on the early implementation of less interventionist approaches 127

10.3.5 Counteract the tendency to shift baselines toward acceptance of higher levels of conservation risk. 128

10.3.6 Ensure that the goals of enhancement are clearly stated. 129

10.3.7 Act on what we do know 130

REFERENCES 131

References cited in the text 131

Other Relevant Resources 142

GLOSSARY 144

ACRONYMS 149

APPENDIX OF DATA 151

APPENDIX 1: NOTE ON THE USE OF U.S. AND CANADIAN STUDIES, EXPERIENCE AND REFERENCES 160

Points of Commonality 160

Points of Difference 160

APPENDIX 2: EVALUATIONS OF THE SALMONID ENHANCEMENT PROGRAM......... 162
General framework for evaluation of SEP projects 162
Evaluations, Consultations and Studies of the 1970s, 1980s and 1990s........ 162
Year 2000 Consultations........ 163
SEP funding........ 163
SEP priorities........ 163
Importance of specific activities........ 163
Implications of the WSP for SEP........ 165
Evaluating and adapting SEP........ 165
User pay........ 165

APPENDIX 3: CHRONOLOGY OF SALMON ENHANCEMENT IN BRITISH COLUMBIA 167

APPENDIX 4: PUTTING ENHANCEMENT INTO AN OVERALL LONG-TERM CONTEXT 169
Sockeye........ 170
Chinook........ 172
Coho........ 175
Chum........ 177
Pink........ 180
Bottom Line........ 181

APPENDIX 5: EXAMPLES OF INTEGRATED APPROACHES TO ENHANCEMENT 183
Clockwork Management: An integrated strategy implemented in B.C. 183
Stave River example of Clockwork Management........ 183
Clockwork Program evaluation........ 184
References........ 184
Rivers/Smith Inlet Restoration........ 184
Results........ 186
References........ 186

TABLE OF FIGURES

Figure 1: Georgia Strait Coho total catch and enhancement releases. 14
Figure 2: The salmon environment, showing diverse sources of impacts on wild salmon and their effect on survival, other than the effects of enhancement 15
Figure 3: The salmon life cycle and related key terms 20
Figure 4: Total output of juvenile chum and sockeye from enhancement. 26
Figure 5: Total output of juvenile chinook, coho and pink from enhancement. 27
Figure 6: The figure shows the location of staffed enhancement projects with significant salmon releases, including estimated fry produced from habitat enhancement Fishways, habitat restoration, lake and stream enrichment, other un-staffed projects and small public involvement and school projects are not shown. 29
Figure 7: Total Restoration releases for chum since 1978. 30
Figure 8: Total Restoration releases for chinook, coho, pink, sockeye and steelhead since 1978. 31
Figure 9: Restoration chum releases by geographic area since 1979. 32
Figure 10: Total Public Involvement Program releases since 1978. 33
Figure 11: Enhancement facility size by species. 40
Figure 12: Coho smolt to adult survival from enhancements in Georgia Strait Vancouver Island (GSVI), Johnstone Strait (JNST), and Southwest Vancouver Island (SWVI) areas. 43
Figure 13: Percent of chinook catch from Canadian enhancement, by area. 44
Figure 14: Number of improved natural habitat projects by project size and species. 52
Figure 15: Numbers of lake enrichment releases and projects over time. 55
Figure 16: Release-to-adult survival of fed chum fry compared to unfed chum fry in the Georgia Strait area. 60
Figure 17: Chinook escapement (log scale) of Kitimat and Kitlope chinook stocks 69
Figure 18: The number of sockeye spawners in Morrison Creek and Lake in the Babine system from 1950 to 2002. 71
Figure 19: Increases in exploitation rate on Cultus Lake sockeye as Weaver Creek sockeye channel stock developed, and associated decline of the Cultus Lake stock 72
Figure 20: Thompson River coho salmon spawners and exploitation rate from 1987 to 2001 return years 73
Figure 21: SEP expenditures from 1977 to 2003. 105
Figure 22: SEP spending on operations (Ops) as compared to spending on studies. 106
Figure 23: Operations and maintenance expenditures in $2003. 107
Figure 24: Shifting baseline syndrome. 129
Figure 25: Number of Improved Natural Habitat Projects by Area and Species 151
Figure 26: Number of Lake Enrichment Projects and Releases by Area in 2002 152
Figure 27: Size of Artificial Habitat Projects for Chum and Coho 153
Figure 28: Size of Artificial Habitat Projects for Chinook, Pink and Sockeye 153
Figure 29: Projects with Artificial Habitat and Natural Spawning and Rearing by Area and Species 154
Figure 30: Hatcheries by Area and Species (Chinook, Coho, Steelhead and Cutthroat) 155
Figure 31: Hatcheries by Area and Species (Chum, Pink and Sockeye) 155
Figure 32: Hatcheries by Size and Species (Chinook, Coho, Steelhead and Cutthroat) 157
Figure 33: Hatcheries by Size and Species (Chum, Pink and Sockeye) 157
Figure 34: Average Releases by Area by Species (Chinook, Coho, Steelhead and Cutthroat) 158
Figure 35: Average Releases (1,000s) of Juvenile Salmon by Area by Species (Chum, Pink and Sockeye) 158
Appendix 4–Figure 1: BC Historic Sockeye Catch 170
Appendix 4–Figure 2: Salmon Catch and Total Adult Returns to Enhancements 171
Appendix 4–Figure 3: Factors Affecting Sockeye Abundance By Ocean Regime Periods 171
Appendix 4–Figure 4: BC Historic Chinook Catch 172
Appendix 4–Figure 5: Enhancement Chinook Releases And Release to Adult Survival 173
Appendix 4–Figure 6: Chinook Percent Enhanced by Major Fisheries 174
Appendix 4–Figure 7: Factors Affecting Chinook Abundance By Ocean Regime Periods 174
Appendix 4–Figure 8: BC Historic Coho Catch 175
Appendix 4–Figure 9: Releases of enhanced coho and release to adult survival 176
Appendix 4–Figure 10: Percent Enhanced Coho by Major Fisheries 176
Appendix 4–Figure 11: Factors Affecting Coho Abundance By Ocean Regime Periods 177
Appendix 4–Figure 12: BC Historic Chum Salmon Catch 177
Appendix 4–Figure 13: Enhancement Chum Releases And Release to Adult Survival 178

Appendix 4–Figure 14: Percent Enhanced Chum by Major Commercial Fisheries 179
Appendix 4–Figure 15: Factors Affecting Chum Abundance By Ocean Regime Periods 179
Appendix 4–Figure 16: BC Historic Pink Salmon Catch 180
Appendix 4–Figure 17: Pink catch (number fish) and estimated enhanced adult production. 181
Appendix 4–Figure 18: Factors Affecting Pink Abundance By Ocean Regime Periods 181

TABLE OF TABLES

Table 1: Common and scientific names of Pacific Salmon. The 'O.' in the name stands for the genus name *Oncorhynchus*. The other name is the species name. 19
Table 2: Salmon hatchery releases from Canada, Japan, Russia, and United States in 1993-2002, in millions of fish (2000-02 are preliminary data). 34
Table 3: Fishways and obstruction removals by area in B.C. 49
Table 4: Number of projects with artificial habitat and natural spawning and rearing (channels). 57
Table 5: Numbers of hatcheries by species and production area in B.C. and Yukon. 61
Table 6: Enhancement methods by species. 63
Table 7: Percent contribution of enhancement types. 64
Table 8: Relative average risk of various types of interactions by enhancement method for large enhancements... 120
Table 9: Relative average risk of various types of interactions by enhancement method for small enhancements.. 121
Table 10: Relative level of concern regarding interactions for each species. 122
Table 11: Number of Improved Natural Habitat Projects by Area and Species 151
Table 12: Size of Artificial Habitat Projects 153
Table 13: Projects with Artificial Habitat and Natural Spawning and Rearing by Area and Species 154
Table 14: Hatcheries by Area and Species 156
Table 15: Hatcheries by Size and Species 157
Table 16: Average Releases (1,000s) of Juvenile Salmon by Area by Species 159

EXECUTIVE SUMMARY

This report provides an objective summary of available information on the impacts of salmon hatcheries and other enhancement activities on wild salmon and steelhead in British Columbia and the Yukon Territory. It explores the opinions and arguments surrounding the impacts of salmon enhancement on wild salmon, and explains the various concepts, theories, practices and research in this field.

Context for enhancement

The initial effort to introduce hatcheries assumed that hatchery-produced fish would simply add to the overall production and compensate for reductions in salmon stocks caused by human and other impacts. The effect of hatchery production, however, has been more complex, with both positive and negative results, especially on wild stocks.

The essence of the debate over hatcheries revolves around the question: If we are producing more salmon, why aren't there more salmon in the ocean?

Several factors apart from hatcheries affect wild salmon. Both wild and enhanced stocks are influenced by harvesting, human impacts on freshwater habitat, and other conditions such as climate change and the hatchery release practices of other North Pacific nations which, in combination, release billions of fish into the ocean each year. Ocean and climatic conditions, in particular, have effects that may be significant but are difficult to distinguish from the impacts of enhancement.

Enhancement methods

Hatcheries are only one element in the portfolio of enhancement activities. Major hatcheries and spawning channels pose the highest risks to wild salmon. Enhancement methods that intervene less in the life cycle of the salmon, such as habitat improvement, are relatively low-risk and generally of benefit to wild salmon. Conversely, the longer the time salmon spend in enhancement facilities, the higher the risk of genetic changes.

The analysis in this report describes the characteristics of different types of enhancement and assesses potential impacts on wild salmon associated with each enhancement method. In order of increasing levels of intervention, these are:

- increased access to natural habitat – obstruction removal;
- improved or restored natural habitat;
- lake and stream enrichment;
- artificial habitat with natural spawning and rearing – channels;
- human-controlled spawning, or human-controlled rearing; and,
- human-controlled spawning and rearing combined – hatcheries.

Other key factors

In addition to the methods of enhancement, several other factors affect the degree of risk posed to wild salmon. These include:

- scale of production and relative production;

- species of wild salmon involved;
- enhancement strategies and practices;
- types of interactions; and,
- knowledge base.

Scale is an important determinant of risk. To some extent, the larger the enhancement activity in terms of the numbers of enhanced fish it adds to the ecosystem, the higher the chance that it will have an impact. *Scale of production* tends to act as a multiplier of some risks. For example, enhancement projects producing large numbers of salmon are more likely to lead to competition for habitat with wild salmon. Composite levels of enhancement from a number of projects in the same area can affect wild salmon as much as a single large project.

However, it is the number of enhanced fish released relative to the wild juvenile production and habitat capacity, rather than the absolute size of an enhancement facility (or cluster of facilities), that more closely determines the potential for adverse interactions between wild and enhanced salmon. This is the influence of *relative production*, which has a pivotal effect on mixed stock fisheries, for example. In enhanced streams and coastal rearing areas, the percentage of salmon production from enhancement ranges from low to high, often depending on the species. Thus, the risks that stem from enhancement also vary.

The risks from the different types of interaction vary significantly according to the *species of wild salmon involved*. The hatchery-enhanced species (chinook, coho, steelhead and cutthroat) generally have the highest potential for adverse interactions. Because wild pink and chum salmon are not generally produced in hatchery environments and do not spend a significant amount of time rearing in fresh water, they have a lower risk of competition, predation, genetic and fish health interactions. Chinook and coho are fished in coastal areas throughout most of their marine life, so they are subject to extensive sequential and mixed stock fisheries. Large production and high survival rates of hatchery chinook and coho can contribute to harvest rates that are too high for wild fish to sustain. Similarly, sockeye salmon from large and highly productive spawning channels can pose a risk that mixed stock fishery exploitation rates will be set too high to maintain the wild stocks.

While the hatchery method of enhancement poses the highest level of risk to wild salmon, the actual risk posed by a hatchery depends upon its *enhancement strategies and practices*, in addition to its size and relative production. The purpose of the hatchery makes a difference – whether it is for production or conservation. Hatcheries are increasingly conservation-oriented, with attendant lower risks. The type of hatchery – whether segregated or integrated – is also important. B.C. hatcheries are increasingly of the integrated type, striving to minimize the differences between the enhanced fish and the wild fish. If effective, integration reduces the risk of genetic impacts.

Another important factor is *operational guidelines*, which can reduce risks significantly. For example, the timing of releases from the hatchery can affect their chances of being caught in mixed stock fisheries. The size of the fish when released influences the extent of competition and predation. Conditions in the hatchery affect fish health, influencing the risk of disease transfer to wild fish. Improved operational guidelines have been introduced, but it is not clear whether or not they are being widely or effectively adopted.

Interactions of enhancement and wild salmon

The factors explained above strongly influence the extent and nature of interactions between enhancement activities and wild salmon. This report examines the theories, arguments and experience related to different types of interaction, listed here in order of the severity of the risk they pose to wild salmon:

- over-harvesting of wild salmon in mixed stock fisheries that include enhanced runs,
- genetic impacts,
- ecological impacts in the form of competition and predation,
- disease, and
- negative impacts on habitat from enhancement facilities.

Mixed stock fishing is at the top of the list because research has identified situations where wild salmon have been negatively affected on a large scale, with the worst impacts related to the Georgia Basin hatcheries. Fishery management strategies and fishing techniques are being directed towards lessening mixed stock harvesting of wild salmon.

Genetic interactions involve serious risks. Although evidence of actual impacts is scarce, current theory indicates that enhancement could significantly reduce the genetic diversity and fitness of wild salmon. Genetic changes to hatchery fish may well be inevitable; the uncertainty relates to how extensive these changes are and how strongly they affect wild salmon. Hatchery practices implemented in recent years have alleviated some risks of genetic impacts, but the risks are still significant.

Competition, predation and health interactions are particularly poorly understood. *Competition* is the third most serious risk. Some studies have pointed to negative impacts on wild salmon, as salmon from enhancement consume food supplies that would otherwise be available to wild salmon. The increasing concerns about limited carrying capacity relate to both freshwater and at-sea habitats.

Predation interactions are a clear risk in theory, and they have been shown to have a negative impact on wild salmon in some cases. Yet, other studies have shown that the presence of enhanced salmon can have a neutral or even positive effect on predation on wild salmon.

No studies illustrating negative *fish health interactions* between enhanced and wild salmon could be found through this research. Nevertheless, the potential for disease transfer between enhanced and wild fish does exist, since conditions in hatcheries can promote the spread of disease, which in theory can then be transferred to wild fish through water or fish-to-fish.

Negative impacts of enhancement facilities on local *fish habitat* are possible, but research has not identified these as being significant. They are the most localized and the easiest of the potential interactions to mitigate or avoid.

Knowledge base

Information on all forms of interaction is incomplete, but with each passing year more becomes known about the complex and interacting factors associated with enhancement activities that create impacts on wild salmon. However, there has been only limited success in applying this knowledge to affect the operations of enhancement facilities and the management of their production and to influence the other factors that impact wild salmon production.

The level of uncertainty and consequent levels of risk regarding potential impacts of enhancement on wild salmon is too high to support the current scale of enhancement activities in British Columbia, particularly in the form of hatcheries. A precautionary approach to hatchery development and management should be taken in the absence of sufficient current research.

The current trend towards insufficient research and inadequate stock assessment should be reversed. Better quality information from monitoring and assessment is essential to make adaptive management possible and effective.

Guiding principles

The report sets out the following seven points that should be used to guide future decisions on enhancement. Together, these suggest an approach to pursuing enhancement objectives while at the same time minimizing impacts on wild salmon. They stress the need to act on the basis of current knowledge, while steadily building better understanding over time, so that solutions can be continually adapted to respond to changing conditions.

1. Operate hatcheries and enhancement facilities with primary regard for their potential impacts on wild salmon.
2. Treat enhancement projects like experiments; learn from the results; and change practices to minimize impacts on wild salmon based on the lessons learned.
3. Undertake research, monitoring and assessment to provide a solid foundation for evaluation of enhancement and adaptive management.
4. Use a combination of enhancement and management strategies to protect wild salmon, focusing on the early implementation of less interventionist approaches.
5. Counteract the tendency to shift baselines toward acceptance of higher levels of conservation risk.
6. Ensure that the goals of enhancement are clearly stated.
7. Act on what we do know.

1. DELVING INTO A CONTENTIOUS SUBJECT

This report was commissioned by the Pacific Fisheries Resource Conservation Council (PFRCC). The scientific advisors for this project were Brian Riddell, Science Advisor to the PFRCC, and Carl Walters, past member of the PFRCC. The aims, rationale, scope and approach of the study are explained below.

1.1 Aiming to clarify conflicting views on enhancement

Hatcheries have been the recent subject of conflicting viewpoints by government agencies, First Nations, scientists and conservation groups. Opposition to hatcheries is gathering, while many continue to defend their benefits. This report aims to provide an objective summary of the potential impact of salmon hatcheries and other enhancement activities on wild salmon and steelhead in British Columbia and the Yukon Territory, to the extent that the existing information base allows. By examining research that has been completed and exploring the information behind conflicting views, this report should advance public understanding and support an informed review of enhancement policies.

The specific objectives of this report are:

- to identify the assertions that have been made about the impacts of enhancement on wild salmon;
- to assess the arguments and supporting information for those assertions in connection with various types of enhancement (not only hatcheries);
- to identify information gaps; and
- to make information about the potential impacts of enhancement on wild salmon available to governments and the public.

1.2 Why is the focus of enhancement on salmon?

Peter Larkin summarized the reasons that salmon are the focus of enhancement in his 1973 essay on Pacific salmon enhancement, "Play it Again Sam." He said that "the general justification" for Pacific salmon enhancement falls into three categories:

1. The social context – people like salmon
2. The economic context – salmon are valuable
3. The biological context – enhancement is possible

These attributes led Larkin to conclude that **"the opportunities for salmon enhancement are enormous."** (1973 p.34, emphasis his) Larkin provided extensive explanation of each of these three justifications. The third is the focus of the discussion here.

The life cycle of the salmon (see Section 2.2) is fundamental to their appeal, and in particular provides the opportunity for enhancement. Salmon grow rapidly to large sizes in the ocean and then return at predictable times to predictable places where they can be harvested. Because salmon naturally spawn in streams, it is easy to intervene in the early stages of their life cycle, and to greatly improve their chances of survival during these freshwater stages. Broodstock or mature adult salmon can easily be captured; eggs can be readily fertilized; and young are easy to raise (Larkin 1973). The surviving adults from the salmon that were released from enhancement facilities can generally be expected to come back to those facilities, providing more broodstock for the next generation, and opportunity for harvest of these fish.

Confidence about enhancement – especially hatcheries – over the years has largely been driven by the ability to increase salmon survival in the juvenile life stages by controlling natural mortality factors (see Section 3 for a description of the evolution of enhancement in North America). For example, in nature the survival of eggs to hatching is approximately 10% while in hatcheries it is approximately 90% (Wood 2002 p.6). The focus on early life stages is key: salmon production could, in theory, be significantly increased by human intervention in the freshwater phases.

In contrast to its success in augmenting freshwater production, enhancement does nothing to alleviate natural limitations on the abundance of adult salmon in the ocean. Only recently has it become broadly accepted that ocean production is not unlimited – the marine environment, like freshwater habitat, has limitations and these limits are not stable through time. Thus, while enhancement may be able to send large numbers of young salmon to sea, it cannot help them once they get there. Furthermore, these enhanced salmon share the ocean environment with wild fish. This shift in awareness does not negate Larkin's third attribute – "enhancement is possible" – but it is a central factor shaking confidence in the potential of salmon enhancement. Ocean production, along with other constraints on the success of enhancement with respect to the welfare of wild salmon, is explored in detail in this report.

1.3 The essence of the debate

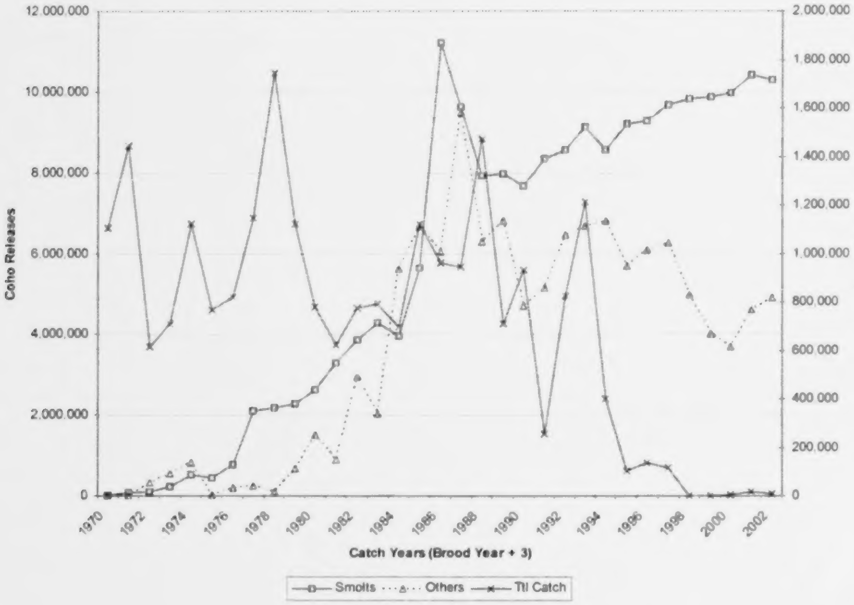
If we are producing more salmon, why aren't there more salmon in the ocean?

Salmon hatcheries were originally intended to increase the survival of young salmon and produce more adults to support fisheries. Yet, despite the significant output of salmon from hatcheries, there has not been a consistent, overall increase in salmon production or catch in fisheries. In some cases, populations of wild salmon have been declining as enhancement has increased.

For example, the percentage of hatchery coho in the Strait of Georgia coho stocks increased from a few percent in the early 1970s to over 70% by 2001 (Sweeting et al. 2003). The increase was a result of both U.S. and Canadian enhanced production. Before recent conservation actions, U.S. origin hatchery coho comprised 25% of the Strait of Georgia sport fishery and a higher percent in the Juan de Fuca area (Coho Steering Committee 1992). Although hatchery releases increased sharply in the 1970s and 1980s, coho catch continued to decline (see Figure 1) and production from local natural populations also declined. The latter led to fishery closures in the Strait of Georgia in the late 1990s. The number of enhanced coho fry, fed fry and pre-smolts coho released has been decreased in the 1990s to reduce competition with wild coho in freshwater.

Figure 1: Georgia Strait Coho total catch and enhancement releases.

The 'Smolts' line is the number of migration-ready enhanced juvenile coho released. The 'Other' line is the total number of enhanced coho fry, fed fry and pre-smolts released. The 'Comm. Catch' line is commercial catch in the Georgia Strait. This does not include sport catch in the area. All information is by brood year. (Source: Release data are from the SEP database and catch data from DFO catch database.)



The basic question arises: "Do hatcheries produce extra fish for harvest, or do they simply replace natural fish with hatchery fish?" (Waples 1999 p.13) In other words: "What, if any, is the contribution of enhancement to the decline in salmon production?"

Some commentators are cautious in assigning blame to hatcheries:

> *"Perhaps because hatcheries in western Canada and United States are typically associated with chinook and coho salmon, and abundance of many stocks of these species has recently declined, the use of hatcheries is being questioned. The technology is blamed per se, despite the success of hatchery-produced pink and chum salmon in British Columbia, Japan, and Alaska." (Perry 1995 p.152-53)*

Others are assertive in their criticism of hatchery impacts:

> *"After more than a century of what one fisheries historian has described as an 'idolatrous' faith in hatcheries, there is still no evidence that hatcheries have contributed to any increase at all in Pacific salmon. Indeed, experience has shown that hatcheries can actually contribute significantly to wild salmon declines ..." (Glavin 2003).*

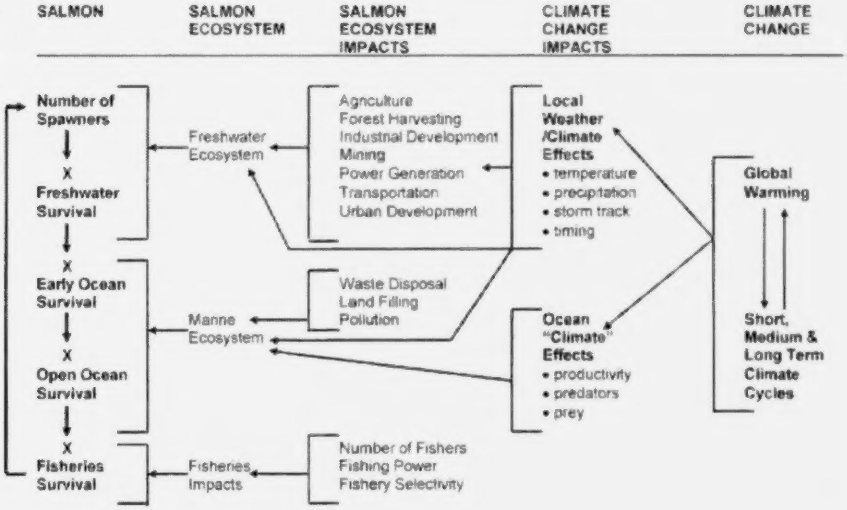
Disagreements between respected scientists reflect the complex challenge of understanding interactions between enhancement and wild salmon. For example, Hilborn and Eggers (2001 p.723) examine data related to hatchery and natural stocks of pink salmon in Prince William Sound and see "strong evidence for the replacement hypothesis." Wertheimer et al. (2001 p.138) look at the same information and assert that the conclusion that hatchery pink salmon have been a replacement for wild production "is not justified."

Hatcheries are only one of many pressures on wild salmon.

Among fishery scientists, attitudes about hatcheries have shifted over the past century from near universal support to widespread skepticism as priorities have shifted to conserving wild salmon rather than supporting runs depending on artificially spawned fish (Lackey 2003 p.51). But does pro-wild necessarily mean anti-hatchery? In some professional groups, hatcheries are being cast in the same light as dams, pollution and climate change, while others see this as "a biased, narrow and unrealistic attitude to fish culture" (Incerpi 1996).

The connections between the various sources of impact on wild salmon are described in Figure 2 – "the salmon environment." The points about "survival" on the left of the diagram are explained in Section 2.2.

Figure 2: The salmon environment, showing diverse sources of impacts on wild salmon and their effect on survival, other than the effects of enhancement


SALMON
SALMON ECOSYSTEM
SALMON ECOSYSTEM IMPACTS
CLIMATE CHANGE IMPACTS
CLIMATE CHANGE
Number of Spawners
X
Freshwater Survival
X
Early Ocean Survival
X
Open Ocean Survival
X
Fisheries Survival
Freshwater Ecosystem
Marine Ecosystem
Fisheries Impacts
Agriculture
Forest Harvesting
Industrial Development
Mining
Power Generation
Transportation
Urban Development
Waste Disposal
Land Filling
Pollution
Number of Fishers
Fishing Power
Fishery Selectivity
Local Weather /Climate Effects
• temperature
• precipitation
• storm track
• timing
Ocean "Climate" Effects
• productivity
• predators
• prey
Global Warming
Short, Medium & Long Term Climate Cycles

Clearly, many human activities other than hatcheries have put wild salmon at risk. The diverse natural and human impacts on salmon survival shown in Figure 2 are often undetected and unmeasured. Fisheries impacts are felt through over-exploitation (also known as over-harvesting or over-utilization), which is affected by the number of fishers, their fishing power, and the extent to which they can harvest specific stocks selectively. Activities that alter, pollute or destroy salmon freshwater habitat include forest harvesting, urban development, industrial development, agriculture, road and rail construction, power generation and mining (Levy et al. 1996, Slaney et al. 1996, Riddell 1993a). Recently, net-cage aquaculture has posed risks to the marine environment (Gardner and Peterson 2003). Other impacts on marine ecosystems include climate change (discussed below), waste disposal, land filling and pollution.

These various sources of impacts can interact to cause unexpected results. This complexity makes it difficult to attribute changes in wild salmon abundance to a specific cause, whether natural or related to development or enhancement. Global warming and long-term climate cycles in particular have had unexpected impacts on salmon ecosystems.

Ocean and climatic conditions have effects that are difficult to distinguish from the impacts of enhancement.

Ocean and climatic conditions have a major influence on salmon abundance (Beamish et al. 1999 p.516). Climate change affects the salmon ecosystem both through local weather effects and effects on the ocean. In the ocean, climate change affects productivity, predators and prey, which are all important to wild salmon. The last climate "regime" was not favorable to ocean productivity, but productivity is increasing under a new regime. One forecast is that this regime will "stimulate modest increases in the size of wild salmon runs" in the early decades of the 21st century, but that "the long-term trend is likely to remain downward" (Hare et al., 1999 in Lackey 2003 p.77).

Some have argued that changes in ocean conditions unfavourable to salmon survival have coincided by chance with hatchery releases, conspiring to make it appear that enhancement has not been successful. Scientists see only the survival rate changes and cannot confidently say whether these are due to the ocean, to enhancement, or to the interactions between the ocean and enhancement.

Hatcheries are only one of several approaches to enhancement.

Concerns about the impacts of *enhancement* on wild salmon centre on large-scale hatcheries. Ecological and genetic interactions of hatchery fish with wild fish are said to have resulted in significant negative impacts, particularly on wild coho and chinook stocks (Noakes et al. 2000). But large-scale enhancement facilities are only one technology in an array of human interventions seeking to increase salmon stocks. Others include the restoration of natural habitat, the removal of obstructions to salmon migration and the fertilization of lakes and streams.

Many questions arise around the nature of interactions between enhanced and wild salmon.

How does the array of enhancement tools have both positive and negative impacts on the production of wild salmon? How do enhanced and wild salmon interact? What are the short and long-term implications? These are the complex questions that this report sets out to explore. More specifically, interactions related to enhancement are examined in terms of direct interactions, in the form of competition, predation, disease and genetics; and indirect interactions, in the form of impacts on habitat for wild salmon, increased harvest rates on wild salmon and masking of changes in production of wild salmon. As these forms of interaction are explored, the foundations of the arguments put forward are examined. To what extent are the problems purely theoretical, and to what extent are they supported by observations? If there are effects on wild salmon, to what extent are these incremental – or additional – to changes that would happen without the presence of enhancement?

Currently available information will not allow definitive answers to these questions. We know that some forms of enhancement pose risks to wild salmon but these risks are not being measured. Despite the uncertainty, enhancement practices continue to intervene in wild salmon stocks. This report aims to highlight key areas of uncertainty while clarifying what we do know.

1.4 Targeting enhancement effects on wild salmon in B.C. and Yukon

This report uses the term enhancement to mean any human intervention that aims to increase the survival or production of salmon or steelhead and cutthroat trout. The term hatchery refers to an enhancement facility that combines captive incubation and rearing (feeding/husbandry) of those fish. Other specific types of enhancement, such as spawning channels and enrichment, will also be examined.

The focus of this research is on the salmonid enhancement activities of the federal and provincial governments in British Columbia and Yukon waters, and their potential impacts on wild salmon. The scope of the research is limited as follows:

- The report does not address the full universe of hatchery, enhancement, habitat protection and related activities. For example, salmon farming and public or classroom education programs about salmon are generally beyond the scope of the report.
- Numerous factors other than enhancement that can have negative effects on salmon are not examined, except to the extent that they interact with enhancement effects. These include freshwater habitat productive capacity, ocean habitat productive capacity and harvest rates.
- Enhancement activities have many benefits that are indirectly related to wild salmon. For example, public education and involvement affect public attitudes and awareness regarding protecting wild salmon and their habitat. Similarly, local enhancements stake a claim for salmon in their watersheds and thereby achieve a higher level of protection for wild salmon habitat. These indirect benefits are not covered in this report.
- The focus is on technological, biological and ecological themes rather than social, economic and legal topics such as allocation and rights aspects.
- The research does not take into account the influence of U.S. enhancement and fishing, from the northwest states or Alaska, on the impacts of enhancement activities in B.C.. Some U.S. examples of interactions between enhancement and wild salmon are included to illustrate points in the analysis.
- This study is not intended to be an assessment of the Salmonid Enhancement Program (SEP). It does not examine program delivery or results as compared to government commitments, nor does it examine costs and benefits. Enhancement activities undertaken outside of SEP are included in the analysis.

For the purposes of this report, wild salmon are those produced by natural spawning in natural habitat from parents that were spawned and reared in natural habitat. There are seven species of concern, which are sub-divided into thousands of distinct spawning populations. Slaney et al. (p.25, 1996) identified approximately 9,500 "stocks" of salmon in B.C. and Yukon (stocks were equated to individual spawning streams).

Enhanced salmon are salmon assisted by humans to increase their numbers by increasing survival, usually in the freshwater life stage. Enhancements are human alterations to natural habitats or applications of artificial culture techniques that are intended to lead to increased abundance of juvenile salmon. See Section 6 for a description of methods of enhancement.

1.5 Overview of approach and contents

1.5.1 Approach

This research is not "primary" in that it did not involve original field studies or modeling. Rather it is a review of previous research and literature synthesizing that research. The research did develop new analyses of previously existing data sets.

A diverse range of literature related to the topics of interest was reviewed. The sources included: books, scientific journals, government (federal, provincial, territorial) and academic reports and studies, and some material from the popular press.

Through a review of databases, the research strived to compile and analyze current and most recent available information for B.C. and Yukon hatcheries and enhancement facilities. Most, though not all, of the databases reviewed are maintained by DFO in its Vancouver and Nanaimo offices. DFO provided access to its databases, including enhancement releases, survivals, catch and other area and project specific data.

1.5.2 Information constraints

Resources for this project did not permit detailed assembly, analysis and reporting on all enhancements relevant to the research objectives. For most projects, there is not enough information to fully assess interactions quantitatively. The analysis is generally limited to identifying potential, or generic, qualitative interactions.

Some information constraints stem from cutbacks in funding to DFO (Fisheries and Oceans Canada) programs that collect data, and changes in policy on assessment and monitoring (see also Sections 8.1 and 8.4.4). A description of key gaps in information and research challenges is provided in Section 9.

Several examples of U.S. experience with enhancement, and results of studies published by U.S. agencies and scientists are drawn upon in this report. There are similarities with Canadian experience, but also important differences which should be taken into account when making comparisons. Points of commonality and differences are summarized in Appendix 1.

1.5.3 Organization of the report

The report is organized into 10 sections, as follows.

- Section 2 provides some basic information about salmon.
- Section 3 describes the roots and evolution of enhancement, bringing us to the present-day situation of increasing concern.
- Section 4, on factors affecting interactions between enhanced and wild salmon, provides the foundation for understanding studies and arguments on the impacts of enhancement.
- Section 5 provides an overview of trends in enhanced salmon production relative to wild salmon production.
- Section 6 explains the range of techniques used in salmonid enhancement in B.C. and Yukon.
- Section 7 analyzes the different ways that enhancement poses risks to wild salmon through six main forms of interaction.
- Section 8 looks at efforts to protect wild salmon from the impacts of enhancement. It reviews programs of monitoring and assessment, measures that can be taken to mitigate potential negative impacts on wild salmon, and reform processes that have aimed to reduce impacts by encouraging the implementation of mitigation measures.
- Section 9 examines information gaps in our knowledge of interactions between enhanced and wild salmon.
- Section 10 estimates the overall levels of risk and provides some conclusions and guiding principles.

2. THE NATURE OF SALMON

Differences between the salmon species and their life cycles result in differences in interactions between enhanced and wild salmon. For example, species such as chinook, coho and steelhead are the most subject to genetic impacts because they are mainly enhanced in hatcheries. Sockeye are susceptible to a disease that limits their rearing in hatcheries, but major spawning channels are used for their enhancement. Pink and chum salmon migrate to the ocean very shortly after emergence from the gravel and are susceptible to predation in the estuary and early ocean life stages. To provide a foundation for understanding the connection between species and enhancement interactions, this section describes the life cycle of the salmon and the seven species of concern. See Section 4.2 for a discussion of differences between hatchery and natural salmon.

2.1 The seven species of salmon

Pacific salmon are in the family Salmonidae and the genus *Oncorhynchus*. Table 1 lists the species by their various names.

Table 1: Common and scientific names of Pacific Salmon. The 'O.' in the name stands for the genus name *Oncorhynchus*. The other name is the species name.

Common Names	Scientific Name
Chinook salmon, king salmon, tyee salmon, spring salmon	*O. tshawytscha*
Coho salmon, silver salmon	*O. kisutch*
Sockeye salmon, red salmon, blueback salmon	*O. nerka*
Chum salmon, dog salmon, calico salmon	*O. keta*
Pink salmon, humpback salmon	*O. gorbuscha*
Steelhead	*O. mykiss*
Coastal cutthroat trout, sea-run cutthroat trout	*O. clarkii*

There are five North American "true salmon": Chinook, Chum, Coho, Pink and Sockeye; and two species of sea-running trout that have similar life histories and are included in the genus *Oncorhynchus* with the five true salmon: Steelhead and sea-run cutthroat. The seven species are collectively called Pacific salmon. The sea-run trout are distinguished from the true salmon mainly by the fact that they do not always die shortly after spawning.

Steelhead and cutthroat are managed provincially; some are enhanced at federal facilities in a cooperative arrangement but the province is in charge of strategies, volumes, etc. There is little information available on cutthroat. The province also operates freshwater hatcheries dealing with rainbow species, which are beyond the scope of this study.

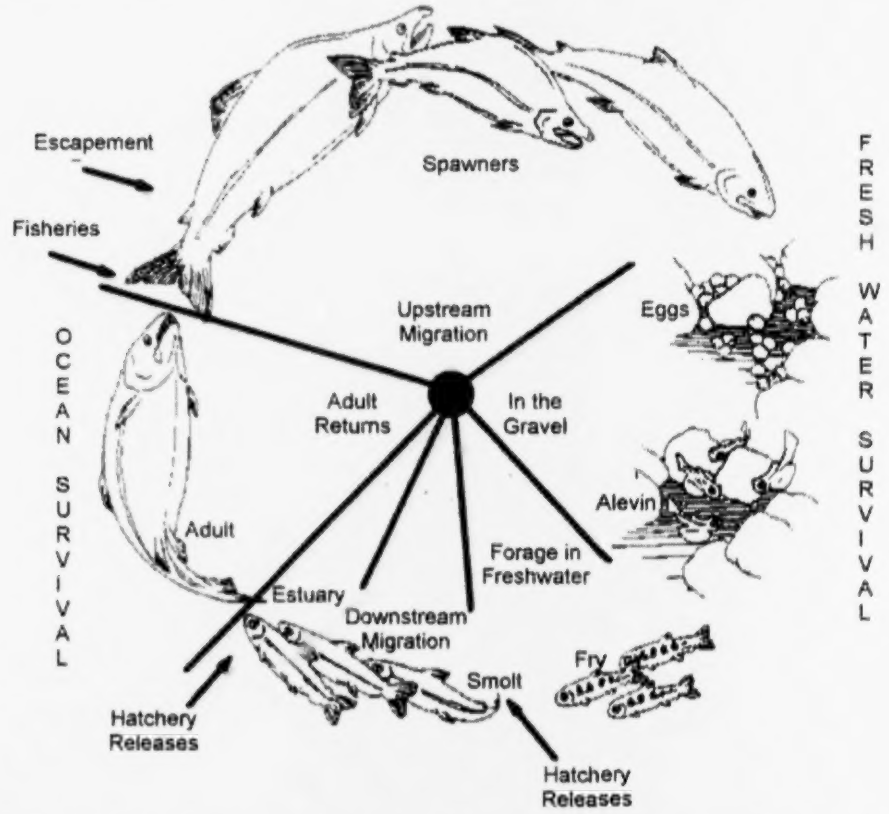
2.2 The life cycle of the salmon

Salmon are anadromous, meaning that reproduction occurs in freshwater, but rearing and growth occur in freshwater and the ocean. Typically, a few weeks to a few years after hatching the young migrate to the ocean; they spend a few months to several years in the ocean; and then they migrate from the ocean to freshwater to spawn. The carcasses of salmon which decay in the watersheds after spawning provide an important source of nutrients for ecosystems which nourish salmon progeny and other freshwater and terrestrial plants and animals.

The various freshwater and ocean life stages of the salmon are portrayed in Figure 3. (The various stages are described below.) The length of time spent in each life stage varies between species. Survival varies in each stage and between species. Most enhancements are aimed at increasing the survival in one or more of the freshwater life stages. Figure 3 also introduces some of the key terms used in discussing enhancement and its interactions with wild salmon, in connection with the salmon life cycle. Note that the Glossary at the end of this report sets out definitions for many other terms used in the report.

Figure 3: The salmon life cycle and related key terms.

Related key terms are: Production = Adult Returns; Escapement = fish that escape the fishery - are not harvested; Exploitation Rate = Harvest Rate = percent of adult returns caught in fisheries; Hatchery Releases = juvenile salmon released from hatcheries.


Escapement
Fisheries
Spawners
FRESH WATER SURVIVAL
Upstream Migration
Eggs
OCEAN SURVIVAL
Adult Returns
In the Gravel
Alevin
Adult
Forage in Freshwater
Estuary
Downstream Migration
Fry
Smolt
Hatchery Releases
Hatchery Releases

Starting with the freshwater phases of the life cycle, in the upstream migration, the adult salmon ready to lay and fertilize eggs are called *spawners*. Salmon may spawn in short coastal rivers, or swim far up rivers to spawning grounds in headwaters thousands of kilometres from the ocean (e.g., Fraser, Skeena, Yukon). Habitat enhancement activities may make it easier for the spawners to travel upstream, via fishways, to their natal streams or to expand their spawning area.

In the wild, the female salmon deposits thousands of eggs in gravel, in a nest called a redd. The male secretes a milky-looking substance called milt, containing sperm, to fertilize the eggs. In hatcheries, the spawners are used as broodstock. The broodstock can be taken from the hatchery stream or they may be transferred to the hatchery from other watersheds. Workers in hatcheries take eggs and milt from the broodstock and conduct the fertilization.

The parents die after spawning (this is called "semelparity") unless they are cutthroat or steelhead trout, some of which may return to sea and come back to spawn again. *Alevins* emerge from eggs and reside in the gravel. They draw nourishment from an attached yolksac for two to three months.

The alevins of wild salmon develop into free swimming juveniles without the yolksac (*fry*) in the gravel of the streambed. Through enhancement, the alevins develop into fry in containers in the hatchery, or in semi-natural or artificial channels that provide safer environments than the natural streambed. The fry may be kept and fed in enhancement facilities, or they may be released. If they are kept, they are later released as fed fry or smolts. The fry or smolts released from the hatchery are called "hatchery releases" or "hatchery production." At this point, the eggs from the hatchery broodstock have produced many more offspring than the eggs in the wild. After release from the hatchery, the life cycle phases for hatchery and wild fish are more similar.

Wild fry emerge from the gravel and either smolt and migrate to the sea right away (pink and chum) or take up residence in freshwater for a few months to a year or more as *parr* (most species).

Smolts are seaward migrants that have undergone the physiological changes necessary to live in salt water. At smoltification, the salmon are ready to begin their downstream migration. Mortalities are high, and the size of smolts migrating to sea directly affects their survival rate in the ocean. Stages from fry to smolt also known as *juveniles*.

Young salmonids stay close to the coastline, usually in estuaries, when they first reach the sea. They generally move out into the open ocean after their first winter, with rates differing depending on the species. Conditions in the estuary and coastal ocean determine the "early ocean survival."

Depending on the species, salmon grow into *adults* between the ages of two and seven years. In the ocean they feed on a variety of prey including plankton, shrimp, squid, anchovies and herring. The hazards of competition, predation and risks to health in the open ocean determine "ocean survival." The salmon from enhancement facilities may have different chances of survival in the ocean than wild salmon, and the mixing of wild and hatchery salmon might affect ocean survival rates.

Sometimes salmon are referred to as *subadult* until they begin to mature. They then begin the migration back to their natal streams. The maturing salmon that return to the coastal areas are known as "adult returns," or as "production." As they return to the nearshore areas they are "harvested" in fisheries and by marine predators. The ones that are not harvested are referred to as "escapement" due to their escaping mortality. During their migration up rivers the salmon may again be harvested in terminal fisheries (i.e., fisheries near their final destination or stream) – mainly by First Nations and sport fishers, as well as by animals such as bears and eagles.

Very few of the original thousands of eggs deposited by a pair of spawners survive through all the life stages to spawn. The numbers of eggs (fecundity), age and size at spawning, and season of spawning are all considered to be adaptations of the species to its environment and the mortalities it typically encounters during a life cycle.

The period or duration of the life stages differs between salmon species. For example, sockeye are unique in that after hatching in the gravel of their stream and lakeshore spawning beds in the spring, the fry move into their nursery lakes and feed on plankton for one or two years before migrating to the ocean as smolts. It should be noted that there is variation in life histories within species and even within systems. For example, some coho in a system feed for a time within the tributaries while others migrate out to sea more quickly (Clarke et al. 1994) and some sockeye that do not have access to lakes must be rearing in streams or estuaries.

In enhancement facilities, different species are held for different lengths of time. Channel produced sockeye, pink and chum salmon are usually not fed and are released as fry. Hatchery produced chum and, to a very limited extent, sockeye and pinks, may be held and fed. Steelhead, cutthroat, chinook and coho are usually fed and raised to fed fry or smolts.

2.3 Production and productivity

Numbers or quantity of salmon, and the strength of salmon populations are often referred to in terms of production and productivity.

Production is the total number of fish surviving to the adult life stage from enhanced or wild sources. The term is generally synonymous with "returns." In the enhancement context, production is sometimes used to mean juvenile salmon produced by a hatchery. To convey this meaning this report usually uses the phrase "enhancement/hatchery *releases*" rather than "enhancement/hatchery *production*."

Productivity is the rate of production per parent in a population. Productivity is frequently expressed as a ratio between the parent and the number of adult progeny they produce.

3. ORIGINS AND EVOLUTION OF ENHANCEMENT

How did enhancement get started and why did it focus on salmon? How has it evolved over the past century, and what shape does it take today? These are the questions pursued in this section of the report.

3.1 The roots of enhancement in North America

For more than a century, hatcheries in North America have been a tool to maintain declining runs and harvest levels resulting from blockage of migratory routes (dams, diversions), loss or degradation of habitat and over-harvest (Waples 1999 p.12, Lichatowich 1999). In addition to these supply limitations, in the early years there was increasing demand to produce salmon to meet burgeoning demand of the many canneries on the Pacific coast of North America. Some people claimed considerable apparent success in the early years of U.S. hatcheries, leading to increases in production of chinook and coho. This apparent success may have been based on incomplete information. In those days it was more difficult than it is today to distinguish wild from enhanced salmon. Closer examination might have revealed less enhancement success.

That time in North American history was a time of technological and economic optimism, especially in a frontier region like the Pacific Northwest. Writers like Lichatowich (1999), Taylor (1999) and others have pointed out that the "man over nature" ethos that drove early enhancement efforts was also driving agricultural and settlement expansion, exploitation of land via forestry and mining, and harnessing of waters via dam building. In fact, some early hatcheries were built so that man could have fish even as other desired activities were destroying them. Many fisheries analysts also felt that ocean carrying capacities were unlimited.

As later sections of this report will illustrate, while enhancement may have provided a short-term visible and apparent quick fix for many problems associated with the growth and development of the West, longer-term effects, in particular on wild stocks, have emerged that are not uniformly positive.

3.2 Enhancement in British Columbia prior to the Salmonid Enhancement Program (SEP)

The first hatcheries in British Columbia operated from the 1890s through the early 1900s. Many facilities were large, with production objectives in the tens of millions per year. The total output of facilities in 1910 – eggs and unfed fry – was about 500 million fish. (Peterson 2002 p.9). It was common practice to transplant fish to these facilities; millions of fish were moved between watersheds (Aro 1979, Withler 1982).

In the early 1920s the Biological Board of Canada reviewed the sockeye hatchery program and recommended that scientific studies be conducted and operations halted until these were complete. More hatcheries were nevertheless built during the period of the research. R.E. Foerster developed a 12-year program covering three generations of sockeye and comparing reproductive methods ranging from natural to intensive artificial propagation. The research was conducted on Cultus Lake and examined factors including reproductive efficiency, survival to migration and adult returns. Foerster found that the more intense forms of enhancement resulted in higher percentages of hatched eggs, but no statistically significant effect on numbers of fish migrating to the ocean (apart from a marginal improvement in escapement if the enhanced fry were fed) (Foerster 1968 and Taylor 1999). This lack of evidence that hatcheries were contributing to overall production led to the closure of all federal hatcheries by 1937 (Taylor 1999). Around the same time, the federal government transferred responsibility for sport fisheries to the Province.

and the sport fish hatcheries were the beginning of the Provincial Fish Culture organization (Peterson 2002).

The mountainous terrain in B.C. focuses urban and industrial development in valley bottoms, where it impacts on freshwater salmon habitat. Over decades of development, the productive capacity in salmon watersheds has been eroded and in some cases stocks have been lost. Proposals for a hydro development on the Fraser River and on other rivers in the province posed additional serious threats.

Rapidly increasing catching power of the commercial fleet, escalating competition between gear-types and high salmon market prices also added to fishing pressure. Meanwhile, the world's first spawning channel was constructed at Jones Creek on the Fraser River near Hope, as mitigation for power development. Also, at this time U.S. fisheries agencies were showing success with their chinoook and coho hatcheries. In the 1960s these developments, as well as a supportive federal Minister of Fisheries, stimulated an ad hoc, facility-by-facility program of enhancement.

Major enhancement facilities were constructed in B.C. at Robertson Creek and the Big Qualicum River. Positive results encouraged further investment. There were soon major projects in the Capilano and Quinsam hatcheries, in the Babine and Fraser spawning channels, and in Hells Gate, Meziadin and Moricetown fishways. New enhancement technologies including lake and stream enrichment, Japanese style hatcheries (which incubate eggs in gravel), and incubation boxes were tested during the late 1960s. All gave early indications of success.

Prior to the development of the Salmonid Enhancement Program there had never been a well-defined program for salmon enhancement for British Columbia as a whole (Larkin 1973 p.8). There were conflicts within DFO over going ahead with some of the above enhancements without a management strategy or the funding to get information for managing existing fisheries and anticipated enhanced production. Most of today's problems had been identified by the mid 1970s, including mixed stock fisheries, differential stock productivity rates, genetic concerns, limited ocean and estuarine capacity, wild and enhanced interactions. The variability of ocean survival was recognized, but not global warming.

3.3 The evolution of the Salmonid Enhancement Program

3.3.1 The early years

The original program proposal leading to the Salmonid Enhancement Program (SEP) was for a sophisticated salmon management program with enhancement to supplement production where it could be managed. The Associate Deputy Fisheries Minister of that time rejected the proposal and had staff replace it with a more politically acceptable program geared towards fish production (Wood pers. com. 2003). The emphasis of fisheries management at the time was Maximum Sustained Yield; habitat management was mainly concerned with immediate impacts. There was little understanding of ecosystem dynamics.

The proposal was reformulated with an enhancement focus, but still with funding for improving fisheries management, particularly of enhanced production. This proposal received two years of funding ($6 million 1975$) to develop a major program proposal. In the two years of planning, an array of issues was looked at, including various enhancement technologies and biological, economic and social considerations.

During that period, important strategies were pilot tested, including the public education program, community economic development, school course material, and technologies such as lake and stream enrichment, Japanese-style hatcheries and various incubation habitat restoration methods. Also during that period, fisheries management biologists worked on new strategies to better manage wild stocks and to harvest enhanced production without impacting wild stocks. Criteria for manageability, "enhanceability" and technical desirability of enhancement projects were developed and agreed to. Considerable attention was given to the need for restoration of habitats and stocks. A number of technologies and approaches for such work were proposed, including stream improvement, lake and stream enrichment, Japanese style hatcheries, semi-natural rearing channels and stream engineering (Fisheries and Marine Service 1977).

Following the planning process, in 1977, a five-year, Phase I of the SEP program was approved with $150 million ($426.7 million in 2003$) funding. The total program of two phases was expected to "eventually result in a doubling of the annual catch of Canada's Pacific salmon." (Fisheries and Marine Service 1977 p.1) The assumption behind this goal (which would increase production by approximately 50 million pounds per year) was that production was at half the capacity it had been at historically (Fisheries and Marine Service 1977 p.57).

Original objectives of the program, delivered jointly with the B.C. government, were to help rebuild Pacific salmon stocks, including sea-run steelhead, and to maintain or increase fishing opportunities. In addition, SEP was intended to contribute to national income, regional development, employment, First Nations well-being and environmental preservation through habitat improvement, restoration and enhancement activities. The requirements for the program included a commitment to implement cost recovery (Fisheries and Marine Service 1977). The economic priorities and commitments forced a heavy investment in projects with the highest projected benefit to cost ratio. This became the driving force for an emphasis on economic efficiency rather than biological effectiveness (Wood pers. comm. 2003). A large budget and short delivery time also favored spending on large capital works such as hatcheries rather than small and semi-natural projects. Rapid inflation in the 1980's also severely eroded the buying power of the SEP budget.

The early emphasis on production for fisheries was reflected in the Cabinet document setting out the rationale for SEP, which stated the B.C. Government position:

> *"The need for an immediate start [on enhancement] stems primarily from the fact that British Columbia's streams cannot continue to be protected for the production of salmonids on the argument of their potential value for fish production if the government is not willing to make a commitment to actually develop this productive potential." (Fisheries and Marine Service 1977 p.10)*

An innovative aspect of the program was the involvement of citizens in 'hands on' activities to revitalize the salmon resource on small, local streams (Pearse 1994). The Community Economic Development Program (CEDP) and Public Involvement Program (PIP) were initiated. They were intended to encourage small community projects that would begin to increase local production, to evaluate the technology and sites, to train community members to operate the projects and to increase local public awareness about salmon and their habitat needs. While the CEDP program has placed contracts with community-based groups to operate local enhancement projects, it did not expand as originally planned, because of the emphasis on large capital works described above. Small-scale projects, while potentially more benign, were difficult to justify on narrow cost-benefit terms, and proved to be inherently more difficult to manage than a small number of large-scale projects. PIP projects were largely not funded by DFO. Their number and extent have increased beyond original expectations.

The government extended Phase I of SEP from five to seven years with no additional funding. There was a general commitment to fund a Phase II if Phase I met its performance targets. The province did not provide direct funding for salmon enhancement and the federal-provincial agreement for the program lapsed in the 1980s.

Phase II of SEP was intended to begin in 1983 but did not begin until 1987 because of budget constraints and increasing controversy over the risks of large-scale enhancement to wild salmon. No new hatchery facilities were built after 1985. A number of facilities, including Quesnel, Eagle and Clearwater hatcheries, that did not meet biological performance objectives were closed, creating financial savings.

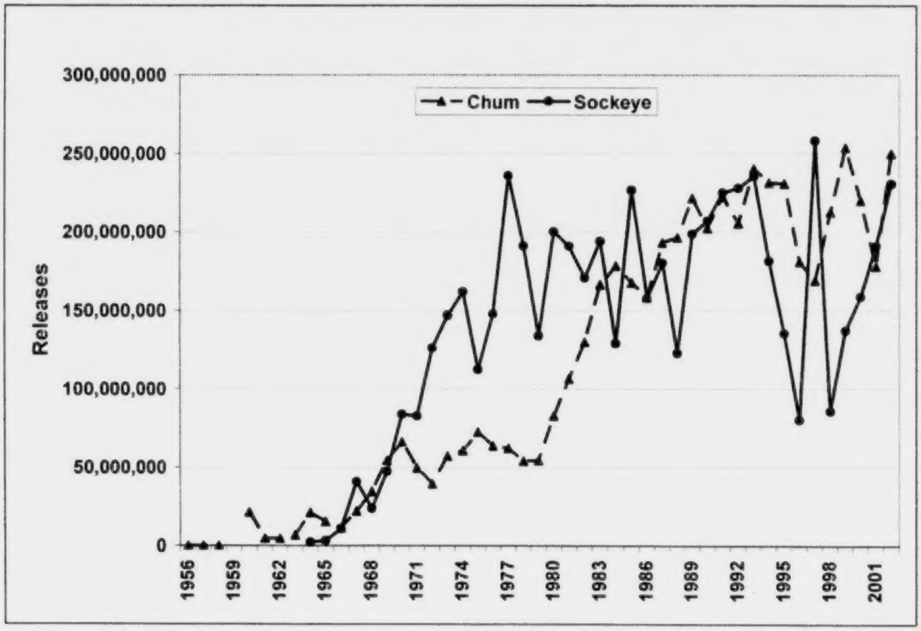
3.3.2 Juvenile salmon releases from enhancement in B.C. over the past half century

Figure 4 and Figure 5 show total output of all sizes of juveniles from enhancement projects for the period 1956 to 2001. For chum and sockeye, the scale of production has been around 200 million per year since the mid-1980s, although the rate is variable. For chinook, coho and pink, the scale of releases is in the order of 20 to 60 million per year.

In Figure 4 the sockeye graph shows the early increase in the 1970s as Babine and Fraser spawning channels came into production. The drop and spike of production in the 1990s is related primarily to changes in production from the Babine channels related to a disease outbreak there and later to disease problems in late run Fraser sockeye. The chum graph shows a steady increase until the mid 1990s when production fluctuated - due to variations in marine survival and returns of adults for broodstock. The fluctuation is related to changing returns and production, as for example in the Big and Little Qualicum facilities that varied from 17 million in 1997 to 65 million in 1999 and down to 13 million in 2001. During the late 1990s and early 2000s chum production hatcheries in the lower Fraser area have decreased production, as stocks were largely rebuilt.

Figure 4: Total output of juvenile chum and sockeye from enhancement.

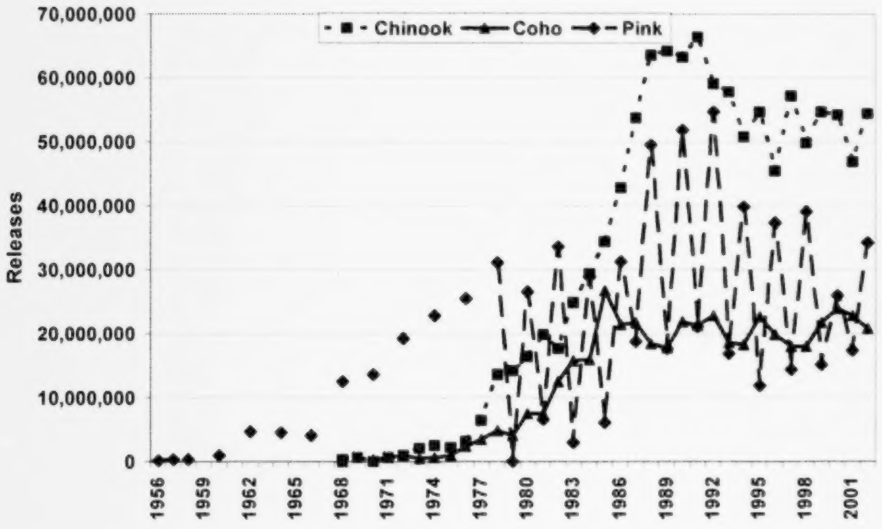
The totals are of all sizes of chum and sockeye juveniles released from all enhancements except from increased access (e.g. by fishways), and also not including sockeye from lake enrichment that are estimated in a different way than other enhancement (see Figure 15). Almost all sockeye releases are from a number of large spawning channels. Chum releases come from diverse enhancement methods including habitat improvement, spawning channels and hatcheries. The large percent of total increases in sockeye populations that resulted from increased access on the Fraser and Babine Rivers is not included in this figure (see Appendix 4: Putting Enhancement into an Overall Long-term Context). (Source of data: SEP database)



In Figure 5 the chinook graph shows a rapid increase in production peaking in 1991 at 66.5 million releases, followed by a decrease to about 52 million from 1994 on. Most chinook and coho releases come from hatcheries and most pink releases come from spawning channels. The percent of coho and pinks releases from habitat restoration is increasing. Coho releases increased until 1985 and stabilized at about 20 million. Pink releases show the even-odd year production pattern related to the fixed two-year life cycle of pink salmon. Pink releases peaked in 1992 and then decreased somewhat. The decreased production in the 1990s is primarily related to fine-tuning of the production strategy (e.g., adjusted production rates to reflect more realistic harvest rates) and closure of some facilities that were not working as intended.

Figure 5: Total output of juvenile chinook, coho and pink from enhancement.

The totals are of all sizes of juveniles released from all enhancements except increased access (e.g. by fishways). Note the relatively smaller number of releases than in Figure 4. (Source of data: SEP database)



3.3.3 Evaluations of SEP

During its existence, SEP has undergone a number of assessments, reviews and evaluations. Some observers have suggested that SEP may be one of the most studied and assessed of all enhancement programs. These assessments, reviews and evaluations dealt primarily with economic and production issues, only secondarily, if at all with impacts on wild salmon. However, even in the 1970s and 1980s, a time of production hatchery emphasis, concerns were raised about the possible impacts of enhancement activity on wild salmon.

A more detailed description of some of the major evaluations is provided in Appendix 2.

3.3.4 Reorganization of SEP into HEB

In 1995-96, SEP was amalgamated with Fisheries and Oceans Canada's Habitat Management Division and the Fraser River Action Plan to become the Habitat and Enhancement Branch (HEB). The goal was to improve the Department's ability to protect and restore fish habitat (e.g., by bringing together habitat management and restoration expertise), and to provide a focus for integrated fish production planning and conservation. Within HEB, the program has continued as the operational arm for federal enhancement and restoration activities.

3.3.5 1998-2003: An Ongoing Series of Changes

Policy and organizational changes and re-assignments of responsibilities have continued over recent years. These have led to difficulties of continuity in budgetary and other matters. For example, between 1990 and 1999 SEP underwent an $11 million (29%) funding cut, from $38 million to $27 million. The key organizational and policy shifts, new directions and reforms, and significant new legislative and regulatory developments of the past five years are described in Section 8.4.

For a summary chronology of salmon enhancement in B.C., please refer to Appendix 3.

3.4 Federal and provincial enhancement in B.C. and Yukon today

3.4.1 Enhancement programs in B.C. and Yukon

DFO operates 16 hatcheries and 5 major spawning channels and maintains more than 50 fishways and unmanned channels. It also contracts 22 community groups to operate hatcheries, 14 of which are Aboriginal communities. As well, DFO funds the Lake Enrichment Program to increase the survival and production of selected sockeye salmon stocks.

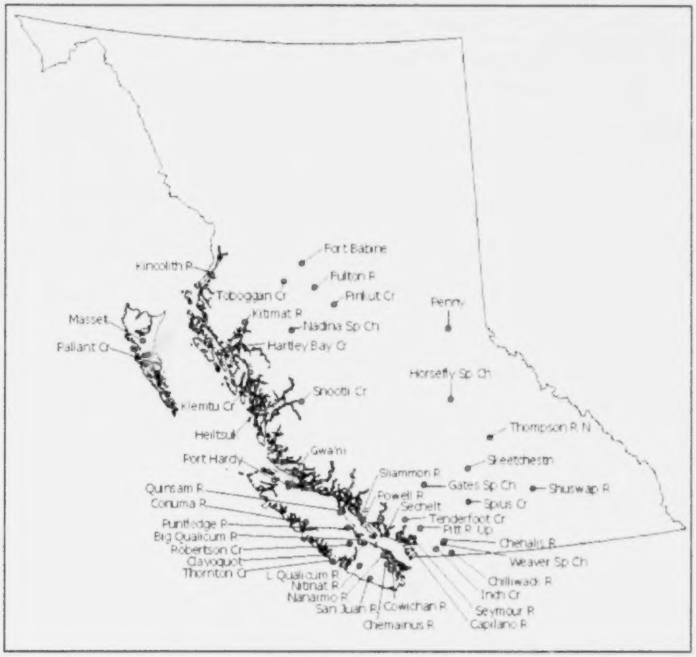
HEB Restoration staff help identify and implement federally funded habitat restoration and improvement projects. They also provide biological, engineering, and technical support for hundreds of jointly or externally funded restoration projects. The province provides support through broodstock capture and stock assessment for steelhead and cutthroat trout.

The program also provides technical and financial support for 200 volunteer projects and 20,000 volunteers. There are 16 community advisors to assist with community enhancement and stewardship projects; an educational initiative for school children (Salmonids in the Classroom); and a Streamkeepers program to facilitate public involvement in fish habitat protection and improvement.

The map in Figure 6 shows the location of enhancement projects in B.C., mainly hatcheries and major spawning channels. It illustrates the large number of projects that release salmon into Georgia Strait.

Figure 6: The figure shows the location of staffed enhancement projects with significant salmon releases, including estimated fry produced from habitat enhancement Fishways, habitat restoration, lake and stream enrichment, other un-staffed projects and small public involvement and school projects are not shown.

Source of data: SEP database


Fort Babine
Kincolith R
Fulton R
Toboggan Cr
Pinkut Cr
Penny
Masset
Kitimat R
Nadina Sp Ch
Pallant Cr
Hartley Bay Cr
Horsefly Sp Ch
Snootli Cr
Klemtu Cr
Thompson R N
Heiltsuk
Gwa'ni
Port Hardy
Skeetchestn
Sliammon R
Quinsam R
Gates Sp Ch
Shuswap R
Conuma R
Powell R
Sechelt
Spius Cr
Tenderfoot Cr
Puntledge R
Pitt R Up
Big Qualicum R
Chehalis R
Robertson Cr
Clayoquot
Weaver Sp Ch
Thornton Cr
L Qualicum R
Nitinat R
Chilliwack R
Nanaimo R
Inch Cr
San Juan R
Cowichan R
Seymour R
Chemainus R
Capilano R

3.4.2 Province of British Columbia programs

The province raises steelhead at 12 federal hatcheries as well as at five community and B.C. Corrections facilities (Peterson 2002 p.11). Two provincial facilities culture steelhead for nine different systems. Almost 1,000 lakes are stocked for recreational fisheries, mainly in trout, char and kokanee. In the pursuit of "harvest augmentation" the province augments approximately 20 systems through steelhead stocking (Peterson 2002 p.13).

In April 2003, the five provincial freshwater fish hatcheries were transferred to a new non-profit society, the Freshwater Fisheries Society of B.C. Together they raise 75 different stocks and strains of seven species of salmonids (Peterson 2002 p. 11). An endowment fund of $2.6 million in one-time funding was allocated to the Society to assist with the operations of the five freshwater fish hatcheries in Duncan, Abbotsford, Clearwater, Bull River and Summerland, as well as fish culture services, including lake and stream stocking and programs to restore fish species at risk.

According to the Ministry of Water, Land and Air Protection, the society will ensure that native fish populations are protected. The province retains authority related to managing the fisheries resource, including legislation, regulation, policy and planning. Ongoing operational funding will be provided through a portion of revenues from angling licences. Funding for conservation services will be provided through a grant from provincial general revenue or through partnerships (MWLAP 2003).

The province's Living Gene Bank Project is striving to assist wild stock recovery through a conservation hatchery on the east coast of Vancouver Island. The research program collects 100 wild smolts from three river systems, rears them to maturity, marks adults and releases them back to their home systems. This will be done for five years (one generation).

3.4.3 SEP releases since 1978

About 600 million juvenile salmon and 850,000 juvenile steelhead and cutthroat trout are released each year from all SEP projects. The annual catch of enhanced salmon is three to four million fish, accounting for 10 to 20 percent of the Pacific salmon harvest.

To provide an idea of recent trends in the level of activity of SEP, releases (numbers of juvenile fish resulting from enhancement) for two program areas are described below. For more information on releases from particular kinds of enhancement, see Section 0.

Figure 7 and Figure 8 show the estimated total releases of juvenile salmon from habitat restoration and improvement projects since 1978 (based on habitat constructed, not counted or hard numbers). Note that the scale of releases for chum is around 100 million, while releases of most other species are under 1.5 million. Resource restoration projects tend to be small scale, semi-natural, unmanned enhancements. These projects often reopen and restore habitat that has been lost to development in the lower portions of watersheds that are most intensively used by chum, coho and pink salmon; however benefits from habitat restoration apply to all salmon species.

Figure 7: Total Restoration releases for chum since 1978.

Releases of juvenile salmon are estimated using standards related to the amount and quality of habitat made available. Resource restoration projects tend to be small scale, semi-natural, unmanned enhancements. As releases of chums are much higher than for other species they are presented in a separate figure. (Source of data: SEP database)

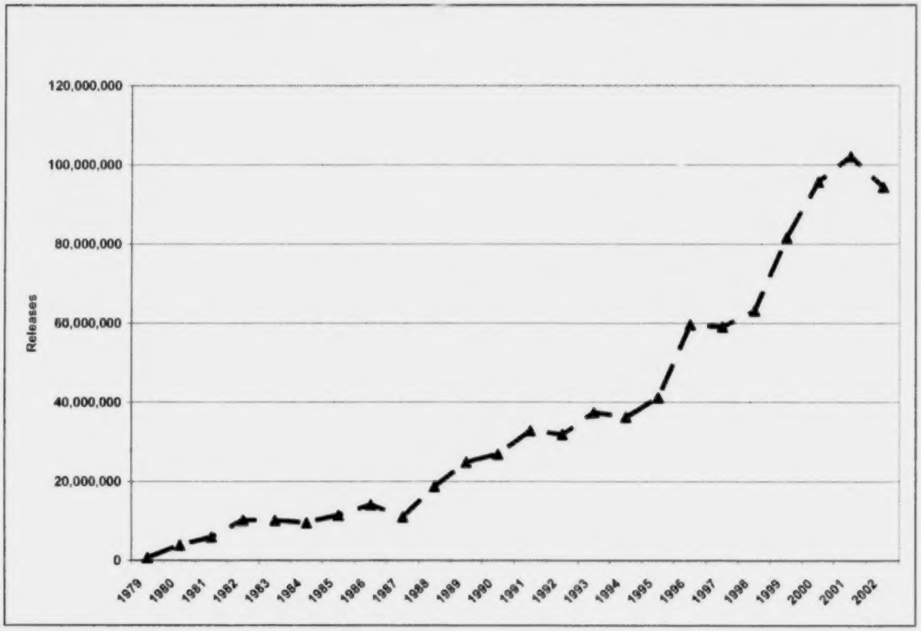


Figure 8: Total Restoration releases for chinook, coho, pink, sockeye and steelhead since 1978.

Releases of juvenile salmon are estimated using standards related to the amount and quality of habitat made available. (Source of data: SEP database)

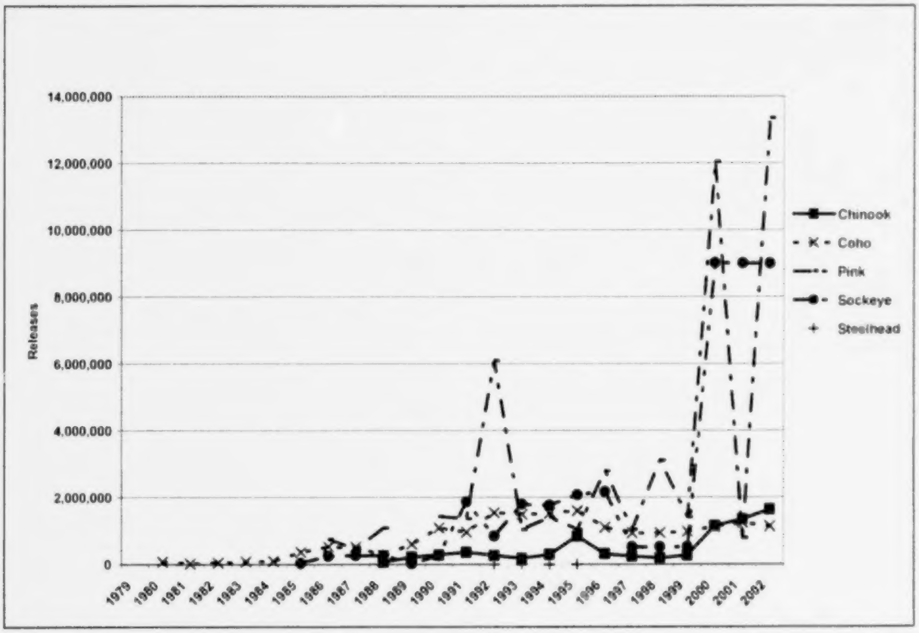
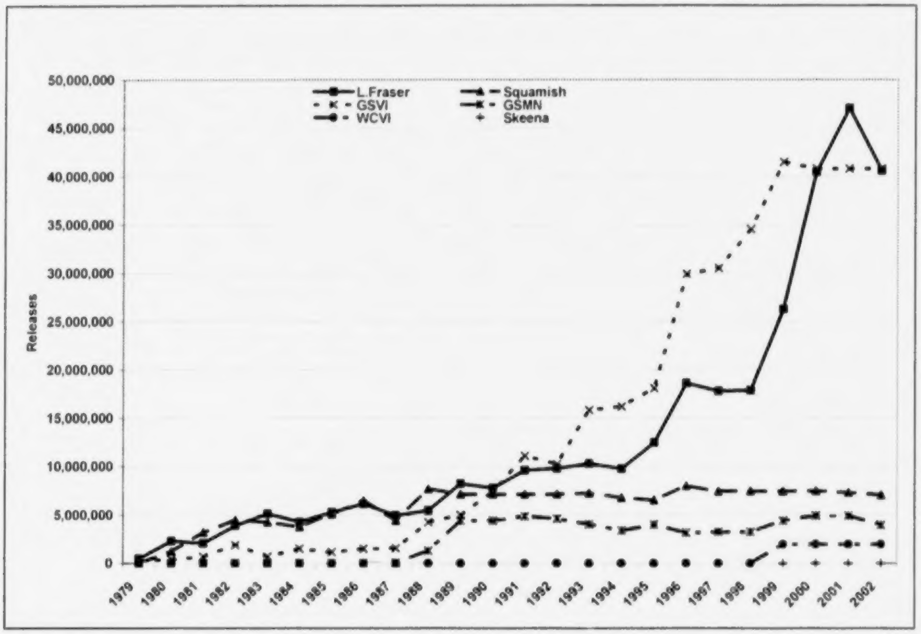


Figure 9 shows that the scale of releases is generally in proportion to the human populations and the amount of spawning habitat lost, with the highest being in the Lower Fraser and Georgia Strait Vancouver Island (GSVI) areas, at over 45 million releases.

Figure 9: Restoration chum releases by geographic area since 1979.

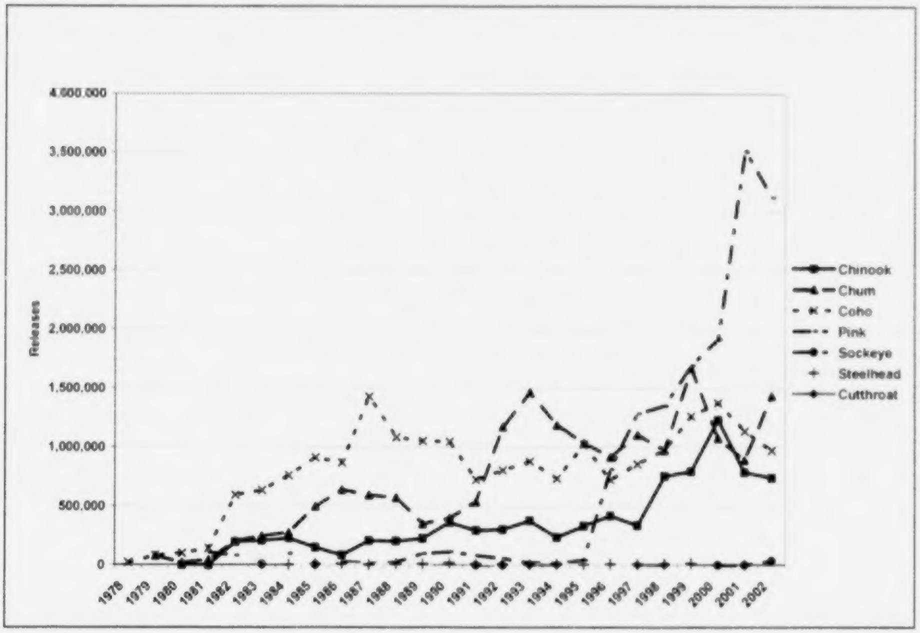
Areas are: L. Fraser = lower Fraser; GSVI = Georgia Strait side of Vancouver Island; WCVI = West Coast of Vancouver Island; Squamish = Squamish River system; GSMN = Northern Mainland portion of Georgia Strait; Skeena = Skeena River system. (Source of data: SEP database)



Releases from facilities operated by volunteers since 1978 are shown in Figure 10. Public involvement projects range from small, privately funded and operated hatcheries to classroom projects that incubate a few hundred salmon eggs. Projects are throughout B.C. and Yukon wherever there are salmon, and include mainly chinook, chum, coho and pink salmon. Beyond the 4 to 5 million salmon released per year, the program builds public awareness and support for protection of salmon habitat.

Figure 10: Total Public Involvement Program releases since 1978.

Source of data: SEP database. Public involvement projects range from small, privately funded and operated hatcheries to classroom projects that incubate a few hundred salmon eggs.



3.5 Emerging problems with enhancement from experience in the North Pacific

Canadian enhancement activity is only one component of the total enhancement activity that results in releases into the North Pacific Ocean. Combined releases from Canada, Russia, Japan and the United States total approximately 5 billion fish per year. Recent research suggests that the carrying capacity of the ocean may be limited, and that the combined releases from all nations may be having adverse effects on the survival of wild salmon.

While fisheries analysts of the 1960s may have concluded that the carrying capacity of the North Pacific Ocean was essentially unlimited, more recent research (Sweeting et al. 2003 and others) is casting doubt on that conclusion. One commentator has compared the ocean to a pasture to make this point: "A potentially serious problem with the hatchery solution is that all the salmon are sent to the same pasture: the North Pacific Ocean. To the extent that the pasture is getting overgrazed, the more new hatcheries we build, the fewer salmon will come back. …" (Buchal 1998 p.147)

Assessing the impacts of enhanced releases on wild stocks should go beyond individual enhancement projects and include composite impacts of all enhancements, both U.S. and Canadian, feeding into water bodies such as the Georgia Strait. Sweeting et al. 2003 found that the composite number of coho released into Georgia Strait might have exceeded the carrying capacity under adverse ocean conditions. The assessment should also go beyond those areas to consider the overall enhancement releases into the North Pacific Ocean. As sockeye, pinks and chums rear in overlapping areas in the North Pacific, enhanced and wild fish from Japan, Russia, USA and Canada all compete. Peterman found an impact of large numbers of sockeye in the Gulf of Alaska on the size of fish returning and possibly their survival (Peterman 1984, Ruggerone et al. 2003).

Table 2, summarizing data provided by the North Pacific Anadromous Fish Commission and DFO's Enhancement Support and Assessment Unit, lists the total enhanced salmon releases from these countries (NPAFC 2003). In total, billions of juvenile salmon are being released to the North Pacific Ocean each year and will compete with naturally produced salmon in the coastal and ocean regions.

Table 2: Salmon hatchery releases from Canada, Japan, Russia, and United States in 1993-2002, in millions of fish (2000-02 are preliminary data).

The 2001 numbers do not include salmon releases from California, Oregon, Washington or Idaho. (Source of data: The North Pacific Anadromous Fish Commission databases)

Species	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Sockeye	380	330	270	211	411	183	240	*232*	*219*	*314*
Pink	1,271	1,222	1,358	1,487	1,253	1,378	1,302	*1,375*	*1,373*	*1,453*
Chum	2,951	2,943	2,986	3,063	2,888	2,830	2,839	*2,787*	*2,680*	*2,821*
Coho	105	113	116	123	111	105	110	*95*	*42*	*94*
Chinook	280	321	350	322	306	292	264	*263*	*55*	*275*
Steelhead	28	32	33	32	31	30	28	*27*	*1*	*NA*
6 species	5,014	4,959	5,112	5,237	4,999	4,818	4,782	4,779	4,369	4,957

The scale of production in the U.S. is much larger than in Canada: "Collectively, salmon hatchery programs in the Pacific Northwest [Washington and Oregon] are very large: hundreds of millions of juvenile fish are released each year from hundreds of facilities." (Waples 1999 p.12) Hatcheries currently contribute between 70% and 80% of the fish in coastal salmon and steelhead fisheries in the U.S. (Northwest Fisheries Science Center 2003).

4. FACTORS AFFECTING INTERACTION BETWEEN ENHANCED AND WILD SALMON

This section outlines the factors or considerations that help us understand the nature of interactions between wild and enhanced salmon, in addition to species and enhancement types. This latter factor, pivotal to the type and degree of interaction, is explored in Section 6. The discussion in this section is not intended to assess interactions or impacts; rather, it is a description of underlying factors.

4.1 The purposes of enhancement

Different enhancement programs have different purposes or objectives. For example:

- SEP objectives are reflected in a suite of benefits against which enhancement facilities are evaluated: economic (benefit-cost ratio), employment, benefits to Aboriginal peoples, public involvement, conservation, assessment, project efficiency and effectiveness, regional development, and sustaining fisheries. Another goal of SEP was to learn by doing – the design of operational practice was to respond to learning through implemented projects.

- The province's overall provincial stocking program objective is to enhance angling opportunity while maintaining a priority on the conservation of wild fish stocks (Peterson 2002 p.11). Enhancement towards "harvest augmentation" involves stocking in the presence of a wild population in order to produce a harvestable product.

- In the U.S. Pacific Northwest, a predominant historical rationale for hatcheries was to mitigate or compensate for losses to salmon runs from impacts such as habitat blockage by dams, to provide continued production for harvest (Lichatowich 1999). The emphasis in the Pacific Northwest today is increasingly on "conservation hatcheries." These are intended to "breed and propagate a stock of fish with equivalent genetic resources of the native stock, and with the full ability to return to reproduce naturally in its native habitat." (Flagg and Nash 1999)

Thus, the purposes of enhancement generally range from enhancing fisheries (production) to enhancing wild fish populations (conservation). In general terms, enhancement focused on *production* may strive to:

- generally increase the survival of juvenile salmon and produce more adults to stabilize and increase fisheries;

- produce fish for selective and/or terminal harvest opportunities, including ocean ranching (large scale releases of smolts to rear in the sea and return principally for harvest);

- mitigate for freshwater habitat loss;

- introduce fish to systems where there were no wild stocks present – colonization (e.g. the province stocks five such systems through steelhead hatcheries) (Peterson 2002 p.13).

Hatcheries with the aim of production have operated in North America for over 100 years. Those aiming to recover wild salmon populations are relatively recent.

Enhancement focused on *conservation or restoration* may aim to:

- supplement at-risk natural populations to sustain, rebuild or recover depleted stocks;

- re-establish extirpated populations – restoration;

- retain remnant stocks at risk of extinction in the short term (e.g. through captive brood programs or live gene banking).

Both production and conservation/restoration may aim to increase the abundance of naturally spawning fish. Conservation goals might be driven by biological or genetic diversity concerns, or they may also have eventual increased harvesting opportunities in mind. Both production and conservation can aim to mitigate declines in wild salmon resulting from various causes, also termed "augmentation" or "supplementation." For long-term conservation goals to be met, the issues that caused the declines need to be identified and corrected while the depressed population is sustained through enhancement.

The different purposes have implications for the methods, scale and timeframe of enhancement. Production hatcheries may establish separate hatchery stocks and segregate hatchery returns from the natural stocks (with the exception of straying), while conservation hatcheries purposefully integrate wild and hatchery fish. Production hatcheries might be expected to operate as long as they are producing fish for harvest, while conservation hatcheries would have a finite lifespan if they are successful:

> *"Clearly the goal of fry augmentation programs is to rebuild the stock to the point where hatchery fry are all surplus to the natural capacity; that is, to put the hatchery out of business." (Perry 1995 p.156)*

4.2 The differences between natural and hatchery habitat

4.2.1 Adaptation to natural environments

Populations of salmon that spawn generation after generation in the same location have adapted to their specific local breeding and rearing environment. Inherited biological attributes of salmon include timing of migration and spawning, juvenile life history and body size and shape (Taylor 1991) and allow managers to define "stocks" of salmon or groups of populations that can be managed together (see Riddell 1993b).

Extinction of salmon is discussed in terms of the loss of stocks rather than species. Stocks must have the ability to respond to their watershed environmental changes, which can be extreme (Lackey 2002 p.42). Genetic variations within and between populations provide the genetic variability that allows for continued adaptation to new environmental conditions. As major environmental changes such as climate change occur, some individuals and even stocks may not be able to adapt but others likely will adapt. Thus, the genetic variation of within and between stocks is key to the long-term survival of salmon species. Many stocks of salmon on North America's Pacific coast have been lost and others are currently at risk (Nehlsen et al. 1991, Baker et al. 1996, Slaney et al. 1996).

4.2.2 Salmon homing and straying

Distinct, locally adapted stocks are able to evolve because salmon return to their parental spawning ground. A small percentage stray from their natal spawning stream and spawn in new areas, meaning that over decades or centuries salmon can occupy empty habitats or reoccupy habitats that have been restored (Lackey 2002 p.42). Some will also stray and mix with salmon in other spawning areas. While this natural process of straying is important to maintain genetic diversity in the wild populations, straying of salmon raised at hatcheries can have a negative impact. If straying of hatchery fish, which are less well adapted to the wild environment, occurs at too high a rate, the continuous influx of genetically different fish can reduce wild stocks' genetic capability to adjust to change. It can also result in the homogenization of local salmon populations. In a sense, high straying of enhanced salmon can inundate or swamp wild stocks. See Section 7.2 for further discussion of straying in relation to enhancement.

4.2.3 Hatchery salmon

Hatchery and natural environments have little in common. The containers in which hatchery salmon rear have lower and more constant water flow than that which occurs in streams and rivers, hold fish at higher densities than those that occur in nature, and are vastly different in food, cover, competitors and predators (Northwest Fisheries Science Center 2003).

These artificial rearing conditions can produce fish distinctly different from wild cohorts. Because all salmon interact with their environment genetically (due to having "high developmental plasticity") they are strongly affected by their rearing environment, including fish in hatcheries (Einum and Fleming 2001). Domestication of hatchery fish implies that fish with different genetic backgrounds respond differently to the hatchery environment. Over time, the survival differences between salmon with different genetic backgrounds develop hatchery fish that are better "adapted" to the their environment … but this also implies they are less well adapted to the natural environment. Brood stock selection and other enhancement processes will also increase genetic differences between hatchery and wild salmon. There was extensive debate in the past about whether differences between hatchery and wild fish were due to genetic change or phenotypic plasticity. The prevailing current understanding is that both are involved, but that genetic change in hatchery fish is unavoidable due to the extensive differences in these environments. The extent of genetic change may be manageable but some genetic change is inevitable. (For more discussion see Section 7.2.)

Hatchery salmon differ from wild salmon in behavior, morphology and physiology (Flagg and Nash 1999). Some examples of differences, as described in Einum and Fleming (2001) include:

- levels of aggression and predator avoidance behaviour – hatchery fish tend to be more aggressive and have a lower response to predation risk;
- timing of migration, which may influence susceptibility to predation, energetic costs and breeding time (which may in turn compromise offspring survival due to inappropriate emergence timing from nests);
- feeding behavior and habitat use (released fish may initially behave inappropriately after being introduced to the stream environment but may acclimate);
- morphological traits, which may be important determinants of breeding success.

4.3 Survival rates by life stage

The production of wild or enhanced salmon is related in a complex way to an array of factors affecting each life stage of the fish (see Section 2.1). Survival rates of salmon are affected by factors such as changes in freshwater habitat, ocean habitat and harvesting. Figure 2 in Section 1.3 illustrates some factors affecting survival in the salmon ecosystem.

Habitat improvement through enhancement can result in more stable natural production for a wild stock by improving freshwater survival, given that wild fish impacted by developments in their watershed probably suffer from reduced productivity. In some cases, restored side channels could be more productive than other natural areas. At hatcheries, various human-controlled factors affect juvenile survival, such as water quality and rearing densities. In general, enhancement protects fish in their early life stages from several factors that cause variation in survival in un-enhanced natural ecosystems. Once the juvenile fish leave enhancement facilities, they are subject to the vagaries of the natural environment, just like the natural populations.

While hatchery fish have vastly higher survival rates in their early life stages than wild fish, they might have higher mortality rates than wild salmon from when they are released as smolts to when they return as adults. In other words, in the freshwater environment, hatchery fish are protected from many of the natural mortality factors that impact wild salmon. When hatchery fish are released, many of those fish that were protected in the hatchery will die because they are not as well prepared for ocean life as wild fish. One of the implications of these differences in survival rates by life cycle stage is that when production from enhancement is assessed in comparison to natural production, differences in lifetime production should be considered – not just the juvenile phases.

4.4 When and where interactions occur

Timing of intervention via enhancement and location of enhancement facilities relative to natural salmon habitat and wild stocks clearly will influence whether there is even an opportunity for enhanced fish to interact with wild salmon. It will also affect the intensity of the interaction (whether genetic, ecological, or related to mixed stock fishing). If enhancement, particularly through major facilities, occurs in places where wild stocks exist, the possibility of ecological and genetic interactions exists.

Different forms of interaction will be of varying concern depending on the arena under consideration. There are three broad arenas of interaction to consider:

1. Enhancement level: within an enhancement facility – processes such as genetic selection and fish health which have implications for wild salmon after the cultured fish are released.
2. Watershed level: within a watershed – ecological interactions such as predation, competition or impacts on the productive capacity of the freshwater habitat; and genetic interactions related to spawning issues. These interactions continue on a broader level in the estuary, coastal and open ocean.
3. Fisheries level: within all the fisheries that the enhanced population is harvested in. This is related to enhanced production impacting harvest rates on wild populations. The main concern is where:
    a) enhanced fish are a significant percent of the total fish in a fishing area,
    b) enhanced fish can sustain a higher harvest rate than wild fish, and
    c) the fisheries are managed for a composite of populations, not specifically for wild fish or for specific populations.

4.5 Technologies and practices

In Section 6, the basic methods of enhancement are reviewed. It is important to note that within each method a range of technologies and practices is applied. Furthermore, practices evolve over time and each facility can be unique. An example of a difference in technology is that in some hatcheries broodstock comes from watersheds other than the one in which the hatchery is located, and the fish produced may be planted back into natal streams. In others, the spawners returning to the hatchery are used as broodstock. These kinds of protocols, and the detailed practices of enhancement which differ between facilities and SEP programs, have an impact on the type and degree of interaction with wild salmon.

Key to the consideration of hatchery impacts is the distinction between the two main hatchery stock strategies: segregated and integrated. In the segregated strategy, the hatchery stock is separate from wild stocks in the area. The separate stock may be introduced or developed by hatchery selection. This strategy is used more in the U.S. than in B.C. Integrated hatcheries use local stocks and expect the interaction and interbreeding of hatchery and wild fish (see Section 6.6.1 for more on this topic).

4.6 Scale of production of salmon from enhancement relative to wild stock abundance

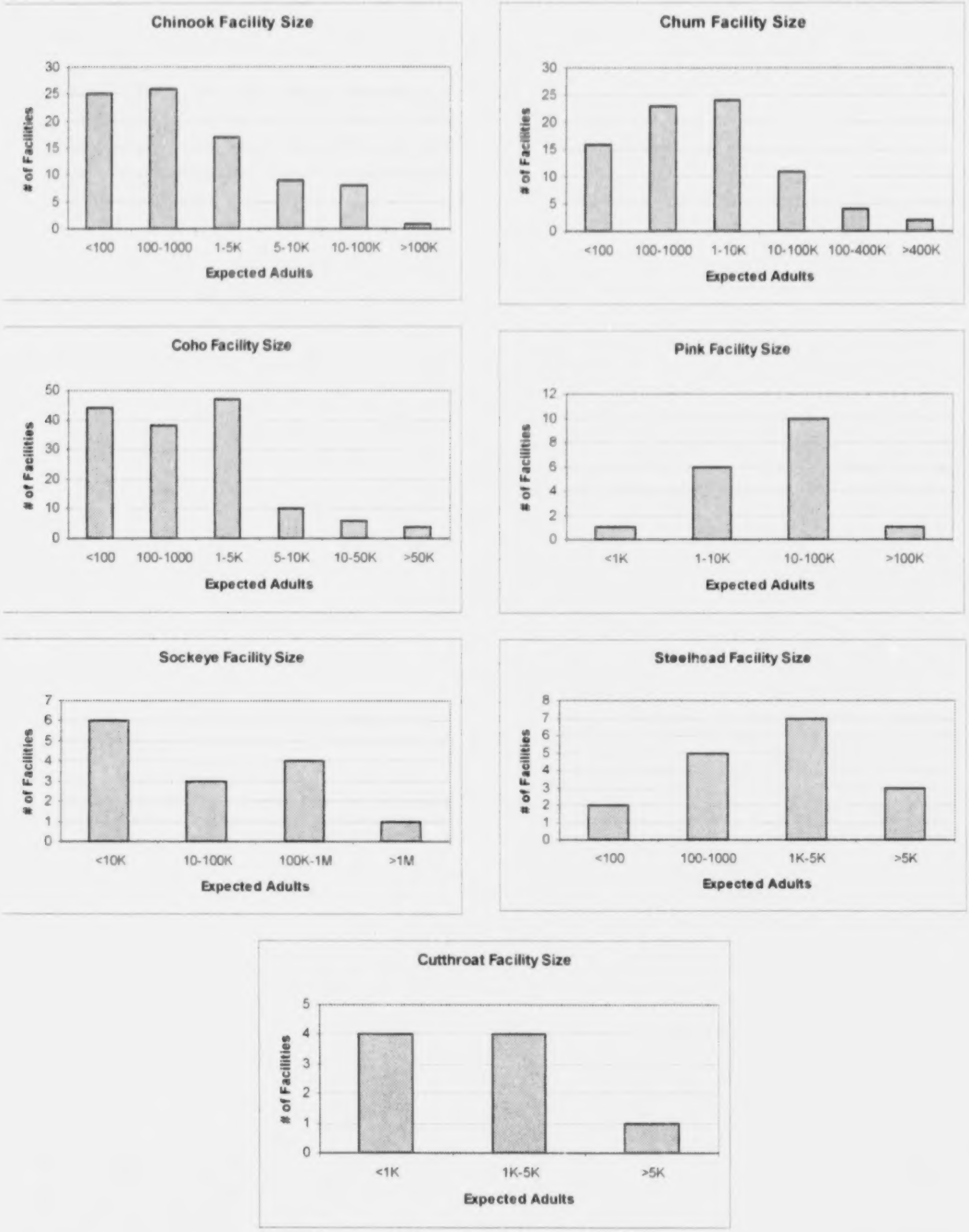
Many of the small enhancement projects account for a small percentage of the total production from the enhanced watershed and involve only single populations of a few species. In contrast, major hatcheries or channels may contribute a large portion of the total salmon production in an area. For segregated production hatcheries that have a "hatchery stock" this could be a concern.

The scale of enhancement relative to the size of the wild population in question has a major influence on the potential impacts of interactions. The impacts of enhancement tend to increase with the abundance of enhanced output relative to that of wild populations, and the number of stocks/populations in the enhanced system. Thus, a large wild population will be more resistant to detrimental interactions with hatchery salmon of a given abundance than will a small population. Conversely, large hatchery release numbers relative to the numbers of wild salmon in the same habitat lead to a higher risk of negative interaction. In other words, the greater the percent of production in a watershed or in a fishery that is enhanced, the greater the potential for negative impacts on the wild populations from enhancement-wild interactions of any sort (competition, predation, health, genetic, or mixed stock fisheries). The greatest concern is with segregated hatcheries. In integrated hatcheries, the scale of production should be matched to the wild populations being supplemented.

Figure 11 shows the size of the various enhancement projects relative to the species of fish they release. It shows, for example, that most facilities releasing chinook are small; however a large portion of the releases comes from the 13 facilities that release more than 1 million chinooks.

Figure 11: Enhancement facility size by species.

For each species, a graph shows the number of facilities by the category of target number of salmon released. For example, for chinook, there are 37 facilities that each release fewer than 100,000 juveniles; 22 facilities that each release between 100,000 and 500,000 juveniles; 5 facilities that each release 500,000 to 1,000,000 juveniles; 14 facilities that each release 1 to 5 million juveniles; and 1 facility that releases more than 5 million juveniles per year. These are the current target releases – actual releases may be higher or lower. (Source of data: SEP database)



Chinook Facility Size

Chum Facility Size

Coho Facility Size

Pink Facility Size

Sockeye Facility Size

Steelhead Facility Size

Cutthroat Facility Size

In situations where wild stocks are very small, the impacts of even small-scale enhancement efforts can pose a risk when enhanced salmon mix with wild. The draft Wild Salmon Policy (DFO 2000) recognized that:

> *"Genetic diversity and fitness are threatened by chance events whenever local population abundance declines to critically low levels. Under these circumstances, short-term intervention to increase abundance will be beneficial if the genetic changes that result from the intervention are less detrimental than the genetic changes that occur from continued low abundance."*

Scale effects also apply at the beginning of the enhancement cycle, in terms of numbers of broodstock taken from a wild population in relation to the size of that population. Use of eggs and milt from broodstock drawn from wild fish populations can diminish wild stocks (Williams et al. 1989 in White et al. 1996), again, particularly when wild populations are small:

"When the hatchery is used to try to rebuild or conserve a severely depressed natural population, fish taken into the hatchery for spawning can represent a high proportion of the total egg production potential for that wild population. From the standpoint of wild population productivity and recruitment, this hatchery removal is then a serious exploitation rate, as surely as if the eggs (and the fish if the hatchery removal is permanent or fatal) had been harvested for consumption." (Walters and Martell, in press, p.3 of ms.)

5. TRENDS IN ENHANCED SALMON PRODUCTION RELATIVE TO WILD SALMON PRODUCTION

In exploring the possible interactions between enhanced and wild salmon, at the broadest level, the first consideration is "Assuming no interaction effects, do enhanced fish survive and return as adults?" This tells us whether enhanced fish will be around to interact with wild salmon, and in which life phases. A related question is "Are the enhanced stocks generally contributing to catch?" These questions are explored in the first section, below.

The next key question is "Are enhanced salmon contributing to an increase in total abundance or are they replacing wild salmon?" And if enhanced salmon are replacing wild salmon, are they compensating for a "natural" decline (caused by poor ocean productivity, habitat loss, etc.), or are they causing the decline in wild salmon? These questions are central to the exploration of interactions between enhancement and wild salmon throughout this report. In Section 5.2 a summary of the various possibilities in connection with relative production is provided.

Section 5.3 focuses on the difficulty of distinguishing ocean effects from impacts of enhancement on wild salmon.

5.1 Contribution of enhancement to production

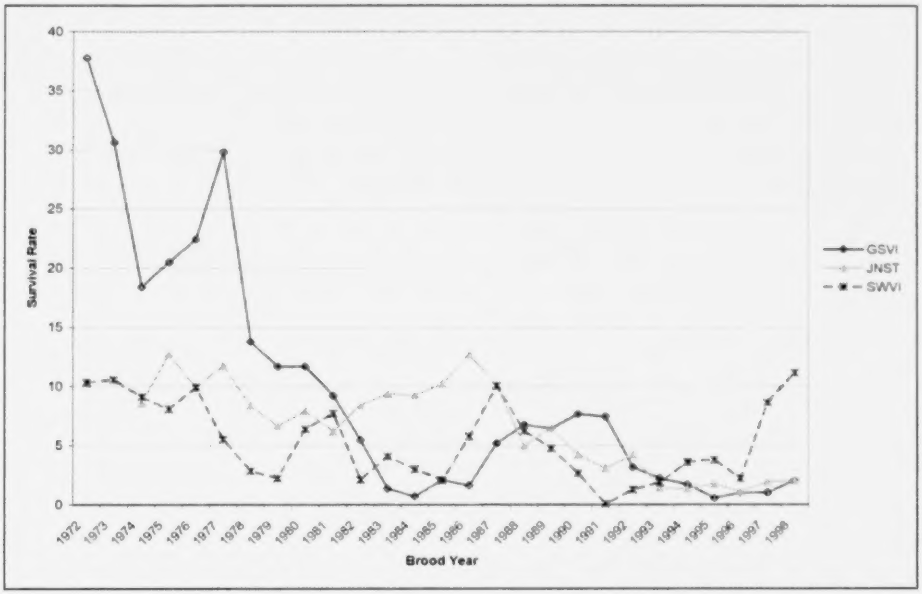
The aim of increasing production through enhancement while striving to minimize impacts on wild stocks leads to a conundrum. Greater success in production potentially causes more impacts. This section helps set the scene around the first part of the conundrum: In general, is enhancement causing production to increase?

Over the decades, critics of enhancement have asserted that hatcheries are not successful even at the most basic level, that is, in *increasing the numbers of adult fish* in the ocean. While hatcheries do provide environments that support high survival in fresh water, the hatchery fish are subject to the same environmental constraints and high mortality rates as wild fish once they are released. An example of the lack of success of enhancement in increasing production is the general decline in coho survival from enhancement in B.C.. .

Figure 12 shows the survival of coho from enhancement, for the stages from smolt to adult, focusing on the three southern areas with the longest data set. The data show a decrease in survival since the 1970s, particularly for the Georgia Strait Vancouver Island area. As there were regime shifts in ocean productivity in 1977 and 1988 it is not clear how much of the decreased survival was from increased hatchery coho production versus changes in ocean carrying capacity (see Appendix 4). The very low survival in all areas in the 1990s is attributed to low ocean productivity that affected all salmon species in most areas of the B.C. coast..

Figure 12: Coho smolt to adult survival from enhancements in Georgia Strait Vancouver Island (GSVI), Johnstone Strait (JNST), and Southwest Vancouver Island (SWVI) areas.

Source of data: SEP database.



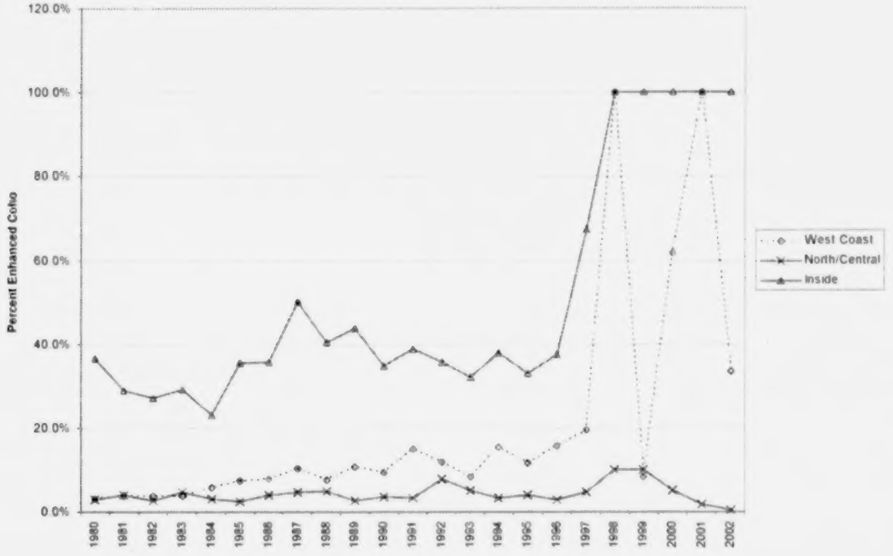
Regarding the ability of hatchery salmon to *contribute to the natural productivity* of wild populations, a review of global experience by Fleming and Petersson (2001) points to negative or inconclusive results. Focusing on breeding success, the study reviewed dozens of studies but found few cases where adequate assessments of enhancement programs have been made. This is at least in part because evaluating the reproductive success of naturally spawning hatchery and wild fish is difficult to do. The few good assessments showed that released fish frequently fail to attain self-sustainability and/or contribute significantly to populations. In other words, naturally spawning hatchery fish do not produce as many surviving progeny as wild fish. The authors found very few examples of successful contributions from released salmonids, and concluded that "all the ecological evidence points to diminished lifetime reproductive success and abilities of hatchery-released salmonids to contribute to natural productivity." (Fleming and Petersson 2001 p.51) They mentioned that two relatively rigorous experiments suggested that released fish have approximately a tenth of the ability of wild fish to contribute to natural productivity, but neither study examined whether the contribution of the released fish added to or simply replaced the natural productivity of the wild fish.

If the focus is on *contribution of enhancement to fisheries* rather than on smolt-to-adult survival or contributions to natural productivity, there is evidence in B.C. that enhancement can have a positive outcome. Hatcheries have provided a substantial component of the coho taken in our fisheries. Catch of B.C. hatchery coho in the B.C. sport and commercial fisheries and the U.S. fisheries ranged from 500 to 650 thousand fish annually from 1986 to 1990, accounting for 10% to 19% of the B.C. coho catch. Hatchery coho contributed 42% of the Strait of Georgia troll and sport catch from 1986 to 1990 (Perry and Kling 1993). This is despite the fact that survival of smolts-to-adult catch and escapement decreased from an average of 15% in the mid 1970s to an average of 7.75% in the mid 1980s (Perry and Kling 1993).

While hatcheries have contributed substantially to coho and chum salmon fisheries, they have made less of a contribution to the fisheries for chinook. Nevertheless, chinook fishery catches have benefited from enhancement. Figure 13 shows the percentage of chinook fishery catches in various areas that were contributed by enhancement from 1976 to 2002.

Figure 13: Percent of chinook catch from Canadian enhancement, by area.

The figure shows the percent of catch of chinooks that were produced from Canadian enhancements and does not include catch from USA enhancements. The catch areas are: Inside = Georgia Strait sport and commercial catch; North Central = area north of the north end of Vancouver Island (commercial catch only); West Coast = west coast of Vancouver Island sport and commercial catch. (Source of data: SEP database)



An example of the contribution of hatchery enhancement to chinook fisheries is the experience of Robertson Creek hatchery in Barkley Sound on the west coast of Vancouver Island. This one hatchery has been extremely successful in chinook production. Important regional fisheries depend on its production, and over 90 percent of the salmon in Robertson Creek are hatchery fish. However, survival rates have varied by two orders of magnitude between brood years owing to variation in marine survival. Annual production has varied by a factor of four, making returns to the dependent fisheries highly uncertain (Riddell 1993a p.342).

5.2 Possible scenarios of relative production

Beyond the question of whether enhancement is increasing the numbers of adult fish in the ocean are questions related to enhanced production relative to wild salmon production. Production resulting from enhancement needs to be examined in the context of the various possible scenarios of relative production listed below. These do not include the situation in which enhancement is the only source of salmon in a watershed. For example, without enhancement at the Capilano Hatchery the river would have few, if any, salmon because the Capilano is an urban river that has been dammed and managed primarily as a GVRD water source.

Possible scenarios if total abundance is declining

- Wild salmon abundance is stable or increasing and declines in enhanced populations explain the total decline. (This might occur when there have been problems in enhancement such as disease outbreaks or if enhancement facilities are closed.)

- Both wild and enhanced stocks are declining at the same rate as the wild stocks would have declined in the absence of the enhanced stocks because all stocks are suffering impacts from the same pressures (e.g. regime shift, over-harvesting).

- Wild stocks are declining at a faster rate than the enhanced stocks. This can happen for either or both of the following reasons:

    - the wild stock is impacted by pressures in their early life phases that do not affect enhanced production as much, such as degradation of freshwater habitat; and/or

    - impacts from enhanced stocks or other enhancement pressures on wild salmon are causing the decline in wild stocks through various processes of interaction.

Possible scenarios if total abundance is staying the same or increasing

- Enhanced and wild salmon are contributing to abundance in the proportions that would be expected based on smolt numbers and expected survival rates (e.g., both are benefiting from the same favorable environmental conditions).

- Enhanced salmon are contributing over the longer term to the natural production of wild populations.

- Wild stocks are declining while enhanced stocks are increasing. This can happen for either or both of the following reasons:

    - the wild stock is impacted by pressures in their early life phases that do not affect enhanced production as much, such as degradation of freshwater habitat; and/or

    - impacts from enhanced stocks or other enhancement pressures on wild salmon are causing the decline in wild stocks through various processes of interaction (discussed in Section 7).

5.3 Distinguishing ocean effects from impacts of enhancement on wild salmon

It is difficult to determine whether or not declines in wild salmon populations can be attributed to the presence of enhanced fish by comparing trends in production or catch with trends in enhancement. Appendix 4, "Putting Enhancement into an Overall Long-term Context" provides an analysis of salmon catch in B.C. through the twentieth century. The analysis provides observations on factors affecting the abundance of various salmon species by ocean regime periods. It shows how trends in catch appear to be related to an array of events or trends related to fishery management and catching power, freshwater habitat, enhancement impacts and ocean productivity. The following discussion looks more closely at the role of ocean productivity, which has received much attention by researchers in recent years.

Analyses often point to environmental conditions in the ocean as a stronger determinant of salmon production than the influence of enhancement. For example, Wertheimer et al. observe a "strong positive and high correlation of hatchery marine survival and returns per spawner of wild stock" (2002 p.70) in Prince William Sound and they ascribe these to conditions in the marine environment. Similarly, Perry and Kling (1993) conclude that parallel trends affecting hatchery and wild stocks from Quinsam River and Black Creek on the east coast of Vancouver Island and from Salmon River and Chilliwack River on the lower Fraser River mean that declining survivals are not simply linked to hatchery practices or outputs. Rather, the production of both hatchery and wild stocks is constrained by other factors that have large-scale impact during the marine rearing stage.

Sweeting et al. (2003) propose that the high percentage of hatchery coho relative to wild coho in the Strait of Georgia in the 1990s may be a consequence of the dramatic decline in marine survival from the mid-1980s to the mid-1990s. Reduced ocean productivity (reduced carrying capacity), in combination with high exploitation rates, reduced wild smolt production so hatchery releases represented an increasing proportion of the total smolt production. As a result of their analysis Sweeting et al. conclude: "… hatchery fish should be considered as ones that interact with wild coho salmon through the natural competitive processes that select the individuals that will successfully occupy the available marine habitat." (2003 p.500)

The issue here is how to partition, distinguish, or separate marine survival issues from changes in enhanced production. Indicator stock data helps to estimate marine survival by stock and brood years. However, we cannot really address the question of interactions because we have never operated hatcheries to provide contrast between changes in marine survival and changes in enhanced production. This is an area that deserves much more research. For coho, there have been comparisons of hatchery marine survival rates and trends versus the wild values … but they are not very consistent in differences. LaBelle et al. (1997) found that marine survival varied between different stocks of coho salmon around the Strait of Georgia and suggested that comparisons of hatchery versus wild differences in marine survival needed to be conducted within a "stock" of coho (i.e., between fish with the same original genetic background).

6. ENHANCEMENT METHODS

In discussing a topic of the breadth of enhancement, the variety of species involved, and differences in personal perspectives, it was not surprising to encounter differences of opinion on how to apply certain terms. For clarification in this report, the following terms will be used with these qualifications:

1. 'Wild salmon'. Section 1.4 defines wild salmon as salmon produced by natural spawning of parents that were spawned and reared in the natural habitat. The intention of defining wild and other salmon would be to differentiate naturally produced fish and human-assisted production of salmon. But this separation is not clear-cut. For example, this chapter will identify enhancement activities that provide access to existing habitat with the objective of increasing the natural spawning and production of salmon. Alternatively, a captive brood program attempts to significantly increase the numbers of salmon in a habitat by maximizing the survival in the previous generation under totally cultured environments. The importance of identifying 'wild' naturally-produced salmon therefore varies depending on the type of enhancement activity employed. However, to assess production attributed to an enhancement program, the issue becomes the differential production of naturally-produced fish before and after the program, or the potential production increase. That issue concerns how 'releases' are used in this text.

2. 'Releases' of salmon imply the production of juveniles and their liberation to natural environments. For hatchery programs or manned channels, these releases can be measured, but how does the term 'release' pertain to increased habitat area or unmanned channels? While we will use releases to infer any juvenile production from an enhancement project, these numbers may be determined in very different ways. Releases from habitat restoration or unmanned channels refer to estimation of potential number of juveniles produced, based on expected numbers of females, eggs per female, and an expected or assumed survival rate from eggs to emigrant stage. Clearly these numbers are much less reliable than known releases from a hatchery, but for presentation purposes, any production associated with an enhancement project will be referred to as 'releases.' But, potential 'release' numbers are highly uncertain on a year-to-year basis.

3. 'SEP' … the Salmonid Enhancement Program. This was the original name of the major federal and provincial program in British Columbia since about 1977. As the program evolved, however, program divisions and the accounting of activities with divisions within SEP changed. The entire SEP was, eventually, integrated into Regional programs. These changes have led to some confusion about how we refer to past SEP activities and numbers of programs, since many of these program names are no longer used. However, since the data provided have, at times, maintained the older designations, we have also used these. SEP no longer exists as a single program branch in DFO and has largely been integrated with localized habitat and fishery operation programs.

We should emphasize that this report is NOT intended as an evaluation of SEP. Rather, the intended purpose is to describe the types of enhancement activities that have been practiced within B.C. and elsewhere. Many people will, however, be familiar with past SEP programs and some consistency of program names may assist their understanding.

A variety of strategies or techniques can be used to achieve the various enhancement objectives (see Section 4.1). Most methods of enhancement are intended to increase the number of salmon by decreasing mortality at a particular early life history stage such as egg-to-fry or fry-to-smolt. Various methods are described below, starting with the least intrusive and moving to the most intrusive (those that control more life history stages). For each method, the technology is described; the number, size and location of projects are discussed where that information is available; and survival rates associated with the method are described, where available.

Percentage figures on survival rates are from bio-technical standards (DFO 1976). These are standard values used for planning purposes by the Salmonid Enhancement Program that were derived from survival rates observed during the 1970s. These standards may not be representative of current values or values specific to some rivers or geographic regions of B.C. and the Yukon. Where survival values have actually been estimated and are available, they are presented.

6.1 Increased access to natural habitat - Obstruction removal

6.1.1 The technology and how it works

Naturally occurring obstructions can block salmon migration, making access to spawning and rearing areas more difficult or impossible. Natural obstructions include logjams, landslides, beaver dams, and changes in stream course such as rapids and waterfalls. Removing or modifying these obstructions, and building fishways to help salmon get above rapids and waterfalls, increases the amount of accessible natural habitat available to salmon by providing access to unused areas. This increased spawning and rearing space can produce more salmon. Methods for providing access range from cutting a channel through a logjam to blasting rocks and building fishways. For example, the fishway on the Bonaparte River opened access to more than 100 km of river to spawning salmon. Fish passage facilities in the Chilko River help sockeye fry migrate upstream into Chilko Lake where they rear. Improving passage not only provides access, but also reduces stresses on fish during their upstream migration, thus improving in-stream survivals and production.

An extreme natural event was the Babine River slide in 1951 that largely blocked access for salmon to Babine Lake. Very few sockeye were able to get past the obstruction to spawn and consequently there were severe reductions in escapement over the next two years (Sprout and Kadowaki 1987). The slide was removed and fish again passed freely upstream. Another example is the installation of a fishway on the Kakweiken River in the 1940s which provided access to an additional 12 km of spawning gravel. In the years when the fishway was operative, permitting passage around a normally impassable falls, pink salmon occupied upriver portions of the river, "thus providing a significantly increased production from that system" (Withler 1982 p.19).

Human-caused impediments to migration such as dams, culverts, dikes, and various water works are often problems for migrating salmon. Culverts under highways and railroads currently block many streams. Continuing maintenance is required to keep habitat capacity available to salmon amid this array of minor obstructions.

The 1913 Hells Gate slide was an extreme example of a human caused river blockage that resulted a dramatic and continuing decrease in Fraser River salmon abundance. A number of fishways and obstruction removals have been required to ameliorate that damage and rebuild stocks. These enhancement efforts have had some success. In 1982 a DFO report stated "The reinvasion by pink salmon of the Fraser River and its tributaries above Hell's Gate following their complete decimation by the slide in 1913 probably represents numerically the greatest modern reinvasion of former territory." (Withler 1982 p.20) Nevertheless, obstructions in the Fraser Canyon remain at certain water levels.

An example of smaller scale enhancement is the removal of dams related to logging on the upper Adams River to reestablish sockeye populations (Williams 1987 p.235). Following egg and fry transplants from 1949 to 1975, further rehabilitation efforts were used to assist the recovery of the sockeye (e.g., short term rearing).

6.1.2 Location of enhancements

A partial list of DFO-managed fishways and obstruction removals by area in B.C. is in Table 3. The species and number of fish that pass through fishways and as a result of obstruction removal varies between sites, ranging from very high passage of most salmon species at Hells Gate to low numbers of a single species in some of the smaller facilities. Most projects involve chum and/or coho and are in the Georgia Basin area.

Table 3: Fishways and obstruction removals by area in B.C.

B.C. Areas, from north to south, are: QCI is Queen Charlotte Islands; NCST = North Coast (Kitimat north); SKNA = Skeena watershed; CCST I= Central Coast (Kitimat to north end of Vancouver Island); JNST = Johnstone Strait; GSMN = Georgia Strait northern mainland; GSVI = Georgia Strait Vancouver Island; LWFR = lower Fraser; UPFR = upper Fraser; NWVI = North West Vancouver Island; SWVI = South West Vancouver Island. (Source of data: SEP data base)

FISHWAYS	AREA	FISHWAYS	AREA
Whitehorse Rapids	Yukon	Millstone Creek	GSVI
Coates Creek	QCI	Salmon River (Campbell River)	GSVI
Fairfax Creek	QCI	Skutz Falls (Cowichan River)	GSVI
Naden River	QCI	Westholme Channel	GSVI
Meziadin River	NCST	Woodhouse Creek (Woodhus)	GSVI
Morse Creek	NCST	Salmon River (Langley)	LWFR
Moricetown Falls (2)	SKNA	Agnes Creek	UPFR
Arnoup Creek	CCST	Bonaparte River and Lake/dam outlet	UPFR
Indian (Canoona) River	CCST	Bridge River	UPFR
Kajustis River	CCST	Cariboo River	UPFR
Koeye River	CCST	Chilcotin R. Farwell Canyon [non-operat]	UPFR
Atlatzi River	JNST	Hells Gate	UPFR
Embley River	JNST	Little Hell's Gate	UPFR
Hemming Lake	JNST	Mitchell River (lake control structure)	UPFR
Kakweiken River	JNST	Saddle Rock (fishway & fish passage)	UPFR
Karmutsen Falls	JNST	Tranquille River (Tranquille?)	UPFR
Mills (Bear) Creek	JNST	Yale Rapids	UPFR
Quatse River	JNST	Marble River	NWVI
Reid Creek [removed]	JNST	Colony Creek	SWVI
Tsulquate River	JNST	Maggie River	SWVI
Wolf Creek	JNST	Sproat River	SWVI
Hastings Creek	GSMN	Stamp Falls	SWVI
Sakinaw Creek	GSMN	Nib Falls	SWVI
Terminal Creek	GSMN	Salmon Creek	
Wilson Creek	GSMN	Schoolhouse Creek	
Cowichan Lake	GSVI	Stotan Falls	

FISHWAYS	AREA	FISHWAYS	AREA
French Creek	GSVI	White Bridge	
Koksilah River	GSVI		

Most of these sites are not staffed and not regularly assessed as to the number of fish using them. The fish production that could be attributable to fish passage projects is difficult to determine. The contribution of fishways and obstruction removals is related to the increase in the percent of populations that can get past an obstruction and the size of the population. It ranges from a significant portion of Fraser River production above Hells Gate to some small stream fishways that pass fish only under adverse water levels. Some of these enhancements have proven ineffective. For example, the Reid Creek fishway was removed because of low use and the Farwell Canyon fishway does not operate because it fills with sand, gravel and debris. Fishways and other forms of improved passage are generally assessed before and immediately after installation. Some fishways, such as at Meziadin and Hells Gate, are used to provide in-season escapement counts that assess fishway performance. Passage of fish past obstructions is also loosely assessed by annual estimates of fish above the obstruction.

6.1.3 Associated survival rates

This type of enhancement is not generally assessed on the basis of survival rates so there is limited quantitative data on the contribution of obstruction removal to survival. However, it is generally assumed that ease of passage reduces stress for up-stream migration, increases access to spawning and rearing space, and mitigates or repairs habitat damaged by debris (land slides, log jams, etc.) or natural barriers.

6.1.4 Overview of obstruction removal and its effects

- Obstruction removal provides increased access to natural habitat, sometimes previously unused habitat, or habitat to which access has been cut off through natural or human-caused events (although maintenance is often necessary to prevent loss of access).
- If the obstruction removal is effectively reversing impacts of human activities, the production may be rebuilding toward historic capacity. Thus obstruction removal results in potentially very large, long-term increased production.
- Improved access could reduce the injuries and stress from difficult upstream migrations, thereby reducing the susceptibility of salmon to some diseases.
- There are no likely genetic or fish health concerns.
- Effects could be reversible by blocking a fishway if required.

6.2 Improved or restored natural habitat

Examples of ways that natural habitat can be "improved" (i.e., to increase production of wild salmon) are spawning and rearing habitat restoration, flow control and temperature control. Such enhancements can increase both the amount of habitat and average survival rates.

6.2.1 The technology and how it works: Habitat restoration

Habitat restoration is achieved by providing improved habitat for salmon to spawn and/or rear naturally. Natural habitat is restored both to increase the usable spawning and rearing space and to improve the quality of previously degraded or low productivity habitat.

Habitat restoration projects are often done through partnerships with community groups, corporations and local governments. For example, B.C. Hydro, the City of Coquitlam and the

North Vancouver Outdoor School have all been long-term partners in salmon recovery and habitat restoration efforts within their respective areas of interest. Priorities for selecting projects have been conservation, restoration, needs of the stocks, the amount of habitat that has been lost, and physical, biological and partnership opportunities.

Projects cover a wide range of project sizes, from improving fish passage at small culverts to the development of critical spawning and rearing habitat in the form of large side channels. Dry channels that parallel river mainstems may be dyked at the upstream end (to keep out seasonal river floods) and dug down so that groundwater will flow into them year round (SEP 1993). Other basic habitat improvements include physical clean-up, placing boulders or gravel, planting vegetation to stabilize stream banks, or eliminating or diverting pollution sources (SEP 1993). Most projects are in areas that have been and will continue to be subject to development impacts, particularly around the Georgia Basin.

The spawning channels in this category of enhancement are un-staffed, semi-natural channels (no concrete involved) that provide somewhat flood-protected spawning conditions, built beside salmon-bearing rivers. They are appropriate in areas which have ample rearing area but limited natural spawning grounds (SEP 1993). Even large stretches of improved spawning areas such as the Stave channel are not staffed.

Estuaries can also be enhanced by restoration efforts. An example is the Englishman River estuary, in which a dyke was breached in order to restore tidal inundation of the north portion of the estuary (Tutty et al. 1983).

6.2.2 The technology and how it works: Temperature and flow control

Control of water flow and – in some cases – temperature, are also used to increase spawning and rearing space and the average survival rates in a few areas. Flood protection reduces the low survivals associated with natural floods. Weirs or dams can be used to control flow or temperature by increasing water storage to allow for increased summer and fall flows and more favorable temperatures.

Another technique used to cool a stream without increasing water use involves drawing water from cool water deep in a lake. Water that is being held for municipal or industrial purposes can also be released or "pulsed" into a river to simulate natural headwaters rainfall. This can get salmon safely through the lower reaches and onto the spawning grounds (SEP 1993). Much planning can go into decisions on flow releases to benefit salmon in side-channel habitats while meeting the needs of water license holders. An early example is the Cowichan-Koksilah Water Management Plan (Burns 1999).

In B.C., flow and temperature control projects have often been implemented in association with other enhancements, such as spawning channels. For example, in both the Nadina River and Gates Creek, the rivers below their lakes have flow and temperature control. On the Big Qualicum River, Robertson Creek, Fulton River and Pinkut Creek, a portion of each river has flow and/or temperature control. In the Nadina River, moderation of summer high temperatures and low flows is important. In Pinkut Creek, moderation of extremely low winter temperatures is also important (Wood pers. comm. 2003).

There are few temperature control projects now, but this form of enhancement may become increasingly important as available water decreases and summer temperatures increase, especially in the southern interior areas such as the Nicola Valley.

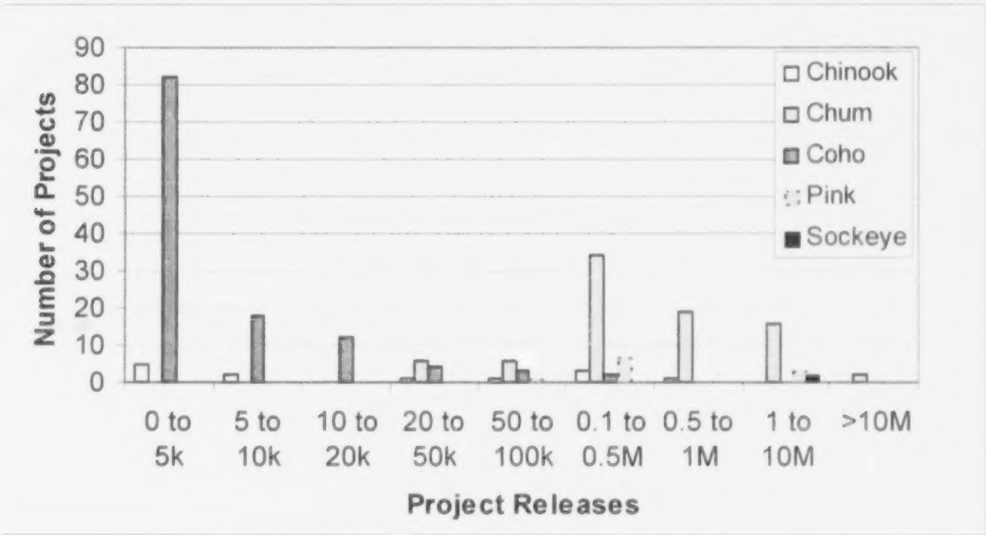
6.2.3 Number, size and location of enhancements

Many habitat restoration projects have opened and cleaned side channels, sloughs and ponds or reconstructed streams for salmon to use for spawning and rearing. Habitat improvement has focused on coho and chum in the Lower Fraser, Georgia Strait Vancouver Island and Mainland areas. The reason is that the low gradient tributaries, in which chum and coho rear, are the most at-risk habitat in the area, and there has been significant loss of habitat to development on the flood plain. This habitat is most subject to development pressures. See Appendix of Data, Figure 1 and Table 1, which illustrate the number of improved natural habitat projects by area and species.

Figure 14 illustrates the number of improved natural habitat projects by project size and species. The juvenile release capacity of these projects ranges from 250 coho to almost 35 million chum. An example of a mid-scale project is Seabird Riffles, which has a capacity of 225,000 juvenile chinook. A smaller project is Spanish Banks, which can produce 30,000 chum and 2,000 coho juveniles. The focus of improved natural habitat is on coho and chum. There are few sockeye projects. There are only about 13 projects involving chinook at present, including gravel replacement at Maria Slough.

Figure 14: Number of improved natural habitat projects by project size and species.

Project size numbers are based on projected juvenile releases based on production standards. The graph shows the number of facilities by the category of number of salmon released for each species. For example, there are 82 projects that each produce fewer than 5,000 coho per year and there are 2 projects that each release more than 10 million juvenile chum. (Source of data: SEP database)



6.2.4 Associated survival rates

Temperature and flow control mainly increase survivals under adverse conditions such as droughts and very hot periods. This type of enhancement tends to reduce the years of low survival more than increasing survival in favorable years.

Salmon produced in improved channels and rearing areas generally have survival rates of about 31% egg-to-fry or to release, and for unfed rearing from 8 to 20% until they emigrate from channels (DFO 1976). These survival rates are slightly better than average natural rates. Many restoration projects also increase the amount of available habitat.

6.2.5 Overview of habitat restoration and its effects

- Habitat improvement provides more habitat for salmon to spawn and rear naturally in.

- Habitat improvement has the potential for small to medium increased production (can be temporary if the improvements do not last).
- Habitat improvement has the potential to increase survival rates, especially in years where stocks in unenhanced areas are subject to flood, drought or other major impacts.
- Habitat improvement is applicable in most areas and for all species.
- If the habitat restoration is effectively reversing impacts of human activities, the production may be rebuilding toward historic capacity.
- Increased production may result in straying of fish produced into other areas within a river system, helping to rebuild populations in unenhanced areas.
- No likely genetic or fish health concerns.

6.2.6 Overview of controlled flow and temperature and their effects

- Water flow and temperature are controlled to increase spawning and rearing space and average survival rates.
- Controlled flow and temperature are usually at a limited scale, and used only in a few areas.
- All species can benefit, but especially stream rearing species such as chinook, coho, steelhead, and cutthroat.
- Controlled flow is especially useful in dry areas to increase spawning and rearing capacity.
- Reservoir storage could affect stream sediments, spawning gravel, and the mix of plants and animals in the stream; however, all temperature and flow control projects in B.C. use lakes to store water.
- Moderating summer and fall water temperatures could reduce the spread of disease amongst spawners.
- Effects could be reversible by stopping flow and temperature control.
- There are no likely genetic concerns.

6.3 Lake and stream enrichment

6.3.1 The technology and how it works

Lake and stream enrichment is intended to increase average survival and size of juvenile salmon by increasing the food supply in the area.

Where there are many spawners and ample spawning areas, productivity may be limited by the amount of feed available for rearing fry. This can be an important factor for species such as sockeye, which rear in lakes for extended periods. If lakes are low in nutrients, they produce little feed for the fry. When spawners die their carcasses add marine-derived nutrients to enrich the freshwater ecosystem. These effects are well documented with respect to stream productivity, while impacts on lakes are less well-defined (Perry 2003). At the time of writing research is underway to determine the effects of high escapements (and thus large numbers of spawners) on Quesnel Lake. Preliminary results strongly suggest, "the lake's productivity and sockeye rearing capacity have been increased by the two years of record escapements and the accompanying increase in nutrient loading from marine-derived nutrients." (Perry 2003) In general, freshwater ecosystems in B.C. are now receiving significantly fewer nutrients from salmon carcasses than they were prior to commercial fishing, when more salmon would return to spawn (Stockner and Ashley 2002).

Lake enrichment involves application of nutrients to a lake to stimulate phytoplankton (microscopic plants) abundance and in turn increase zooplankton (small animals) growth and abundance, thereby providing increased food for juvenile sockeye rearing in the lake. Increased growth of salmon in freshwater should result in improved marine survival and numbers of returning adults.

DFO began a large lake enrichment program in 1975, aerially fertilizing selected sockeye nursery lakes. Over the last three decades, about 25 lakes have been fertilized weekly (Stockner and Ashley 2002). Fertilizers (nitrogen and phosphorus) are applied weekly from early spring to late fall to promote increased growth of these basic components of the salmonid food chain (SEP 1993). The mix, timing and distribution of nutrients added must match the lake conditions to ensure that sockeye food organisms are increased. For example, in experiments in Woss Lake, the phytoplankton that initially responded to the enrichment was not part of the sockeye food chain.

A key factor affecting the feasibility of lake enrichment is the productive capacity of the nursery lakes (Shortreed et al. 2001). If freshwater habitat factors other than nutrient supply are limiting production, enrichment is unlikely to be effective. Furthermore, nutrient addition does not increase sockeye salmon abundance in every lake because some sockeye populations are limited by factors outside of their freshwater growth phase such as fishing pressure, spawning habitat, predation or competing species (HEB website 2003).

Stream enrichment, like lake enrichment, involves adding nutrients to stimulate aquatic plants and in turn animals that stream-rearing salmon species feed on. This would benefit mainly steelhead, cutthroat, coho, chinook and resident trout. Stream enrichment does not have to be as prescriptive to each individual stream as lake enrichment. Stream enrichment would usually benefit all stream rearing species by increasing the productivity of the stream.

6.3.2 Number, size and location of enhancements

The scale of possible sockeye production is related to the size of the lake, the percent increase in needed nutrients, and the size of sockeye population rearing there. Large lakes such as Chilko Lake are estimated to have produced more than 19 million incremental smolts of a total of 200 million in peak years, while smaller lakes produce fewer (Bradford et al. 2000). The estimated increase in the number of smolts resulting from lake enrichment has varied widely, with recent releases estimated at about 5 million sockeye smolts.

Figure 15 shows numbers of enrichment projects by release size over time. As might be expected, as the number of projects decreased, the production decreased. This production in only associated with actual programs and not lakes that may have historically been enriched.

Figure 15: Numbers of lake enrichment releases and projects over time.

Source of data: SEP database

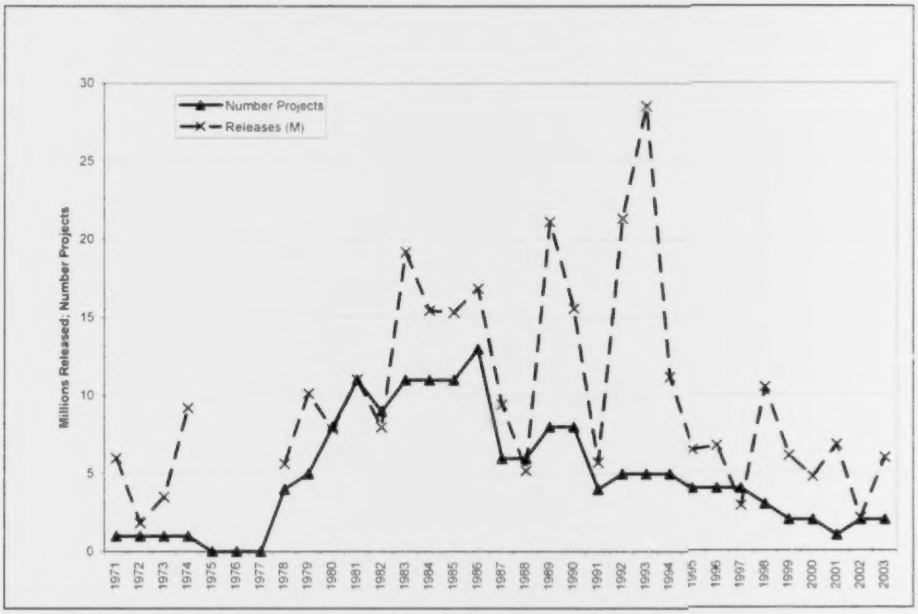


Figure 2 in the Appendix of Data shows the 16 lake enrichment projects and releases by area in 2002. The longest-running enriched lakes were: Great Central, Henderson, Hobiton, Long and Kennedy. The number of lake enrichment projects peaked in 1986 with 13 lakes being enriched. Based on enrichment results, costs and decreasing enhancement funding, the number of lakes enriched has decreased to two – Great Central and Woss Lakes.

As lake enrichment efforts in B.C. have diminished, stream enrichment remains a relatively new area of enhancement. Data on the numbers of stream enrichment projects are not available. Specific projects are highlighted in the next section.

6.3.3 Associated survival rates

Lake and stream enrichment generally result in higher average freshwater survivals than would occur in the same natural habitat without the enhancements. Lake enrichment has been found to increase both the number of sockeye produced and their average size. The increased size should give them a survival advantage in later life.

The increased adult production resulting from lake enrichment has been estimated to be double the natural production as a result of increased numbers of smolts, and increased average size and survival of smolts. There have been questions whether changes in sockeye production should be attributed to enrichment and, after a population has increased to a significantly higher level, if it could sustain itself at that level without enrichment.

Chilko Lake enrichment has been assessed. The researchers estimated that the mean recruits per spawner of fertilized broods was 73% higher than unfertilized broods, but acknowledged considerable uncertainty in this estimate (90% confidence interval of -2% to 174%, Bradford et al. 2000 p.666). They further observed, "in years when Chilko Lake was fertilized, both the size and marine survival of sockeye salmon smolts appeared to increase." (Bradford et al. 2000 p.669) Evidence for increase in adult production was not strong but there was some evidence for improved adult returns as a result of increased smolt size through nutrient enhancement.

Initial indications of an assessment of Henderson Lake enrichment are that it also made a difference in both the number of recruits per spawner and their average size (pers. comm. Hyatt 2003).

Experiments with fertilization of rivers also illustrate benefits of fertilization. Ward et al. (2003) found positive responses in steelhead and coho in juvenile abundance and size, smolt yield, and smolts per spawner from a combination of fertilization and other restoration activities in the Keogh River. Slaney et al. (2003) reported that the weight of steelhead trout and coho salmon fry increased after nutrient addition to the Keogh River (1.4-2-fold higher than the control). Weights of steelhead parr also increased, and steelhead smolt yield in three brood years increased 62%. There were corresponding increases in returning adults. When nutrient addition ceased, there was a return to near-average smolt yields. On the basis of these positive results fertilization was applied in the Salmon River and and Slaney et al. (2003) found that even with lower amounts of nutrients the size and numbers of steelhead increased.

Stockner and Ashley (2002) conclude a review of lake and stream enrichment studies by saying: "Nutrient enrichment has proven to be an effective habitat restoration and enhancement tool, increasing fish production in oligotrophic lakes and streams in British Columbia and Alaska."

6.3.4 Overview of lake enrichment and its effects

- Lake enrichment increases average survival and size of juvenile salmon by increasing the food supply through adding nutrients to lakes.
- Lake enrichment is currently conducted on a limited scale.
- Sockeye are the target species (the only salmonid species involved), as they rear in lakes.
- Lake enrichment could result in increases in species that prey on sockeye.
- Lake enrichment can alter the ecosystem balance (e.g. sockeye vs. sticklebacks, plankton mix).
- Lake enrichment generally enhances all fish rearing in an enriched lake, and if fisheries are based on recruitment from that lake, mixed stock fishery problems do not result. If stocks from an enriched lake combine with stocks from un-enriched systems, mixed stock problems can result.
- There are no likely genetic and minimal health issues.
- Effects are assumed to be reversible by stopping enrichment.

6.3.5 Overview of stream enrichment and its effects

- Stream enrichment increases average survival and size of juvenile salmon by increasing the food supply through adding nutrients to streams.
- Stream enrichment is currently on a limited scale.
- Stream enrichment could be used to increase the productivity of otherwise unenhanced populations to moderate the differences between wild production and hatchery releases.
- Stream enrichment could alter ecosystem balance, e.g., by increasing species that prey on some salmon species (particularly pinks and chums) and on other fish species.

- Stream enrichment is not likely to aggravate mixed stock fisheries problems on an individual stream basis. However, widespread stream enrichment over long periods of time can result in mixed stock problems.
- There are no likely genetic or health issues.
- Effects are assumed to be reversible by stopping enrichment.

6.4 Artificial habitat with natural spawning and rearing – Channels

6.4.1 The technology and how it works

This type of enhancement refers to the provision of habitat for salmon to spawn and rear in naturally. Man-made spawning and rearing channels (as opposed to the natural channels that may be restored or improved, discussed in Section 6.2.1) provide additional habitat in which salmon survivals are higher than in natural areas of the same watershed. Spawning channels provide clean, uniform spawning gravel and often controlled water flow and temperature to reduce the impacts of flooding, droughts, freezing and over-heating. Predation may also be limited. Rearing channels provide productive habitats for stream rearing species.

Adult salmon may be encouraged to enter the channels by fences or weirs, although fish often home to the channels. Access to some spawning channels is controlled to prevent too many spawners and decreased survivals. In managed spawning channels, flows, spawning densities and spawn timing can be controlled. Spawning timing in the channel is decided by loading early, mid or late timing portions of a run into the channel. The water into most spawning channels is turned off after the fry leave and until the adults return. This is to help control algal growth and keep maintenance costs down. This means that in most spawning channels there is no rearing. In some channels, groundwater flow is enough for at least some rearing.

6.4.2 Number, size and location of enhancements

There are significant differences in the size of channels for the different salmon species. Coho and chinook channels tend to be small. Pink and chum channels have mid-sized releases, with many projects releasing from 100,000 to 500,000 juveniles. Sockeye channels are largest, with the Babine channels releasing more than 100 million sockeye fry. Figures 3 and 4 and Table 2 in the Appendix of Data illustrate the size of artificial habitat projects by species.

The distribution of channels is illustrated in Table 4. Figure 5 and Table 3 in the Appendix of Data illustrate projects with artificial habitat by area and species. Most of the projects are in the Georgia Basin area, where urban and industrial development and intensive fisheries have had the most serious impacts. The differences in geographic distribution of projects for each species are related to species and area differences. For example, most of the large sockeye channels in the Skeena and Fraser systems, where most of the sockeye production is, are generally related to the large lakes with underutilized rearing capacity. Some, however, have been built to mitigate for logging damage or for dams. Most projects are for chum and/or coho and most are in the Georgia Basin area.

Table 4: Number of projects with artificial habitat and natural spawning and rearing (channels).

The production areas from north to south are: SKNA = Skeena watershed; JNST = Johnstone Strait; GSMN = Georgia Strait northern mainland; GSVI = Georgia Strait Vancouver Island; LWFR = lower Fraser; TOMM = Thompson River mainstem; TOMF = Thompson Forks (North and South Thompson). (Source of data: SEP data base)

Area	Chinook	Chum	Coho	Pink	Sockeye
SKNA			1		3

GSVI	2	2	3		
LWFR		1		1	1
UPFR					3
TOTAL	2	3	4	1	7
Releases(M)	6.24	94.7	1.581	0.92	205.3

6.4.3 Associated survival rates

Spawning channel egg-to-fry survivals are about 50% for highly controlled channels, as compared to an average 15% for natural spawning areas (DFO 1976). There is a considerable range of survival rates between channels. For example, typical survivals for the Babine channels are 20 to 45 percent.

6.4.4 Overview of spawning channels and their effects

- Effective spawning channels provide clean, uniform spawning gravel and often controlled water flow and temperature to reduce the impacts of flooding, droughts, freezing and over-heating.
- Spawning channels range from small to large-scale production.
- Facilities may benefit various species, depending how they are operated.
- Accurate homing of spawning populations might result in a highly productive channel population dominating other populations in the watershed or in the fisheries within which the enhanced population is harvested, possibly resulting in genetic and mixed stock fishery interactions with wild salmon.
- Increased production will likely attract an array of predators, especially if the increased production is consistent between years.
- Health issues are unlikely to differ significantly from those in natural environments, except to the extent that crowding could increase the spread of disease among fish in channels.
- Project-specific risk of loss of water flow could put the fish using the channel at risk. This could only occur where the water flow might be stopped by a blocked water intake or pump or pipeline failure.

6.4.5 Overview of rearing channels and ponds and their effects

- Rearing channels provide productive habitats for stream rearing species.
- Rearing channels usually result in small-scale production.
- Facilities may benefit various species, depending how they are operated.
- Rearing channels could increase the amount of predation on other species in the watershed.
- There are no likely genetic issues if the enhanced fish do not home to the rearing area – any behavioral changes resulting from the artificial rearing environment are not likely to affect more than a single generation.
- Health issues are unlikely to differ significantly from those in natural environments.

- Project-specific risk of loss of water flow could put the fish using the channel at risk. This would only be a risk where the water flow could be stopped by a blocked water intake or pump or pipeline failure.

6.5 Human controlled spawning, or human controlled rearing

Human controlled spawning and human controlled feeding can be used independently or together – as in hatcheries. In this section the two are discussed in terms of their independent use, although this is less frequent than combined use in hatcheries. Individual spawning or feeding projects tend to be small and only intervene in a single life stage – as contrasted with hatcheries, which intervene in a number of life stages and range in size from small to very large.

6.5.1 Human controlled spawning - Incubation

Human controlled spawning involves taking salmon eggs, fertilizing them (based on the availability of ripe parents), and incubating them in an artificial environment. Eggs are usually treated with disinfectant to reduce possible disease. Various types of incubation boxes, troughs or other incubation enhancement techniques can significantly increase survivals above natural rates. In some cases, small batches of fertilized eggs have been planted in gravel in a stream to incubate naturally.

In-stream incubators were developed by SEP staff to solve cold-weather incubation problems common in northern B.C. and Yukon. "Cassettes," filled with eggs which have been fertilized in a hatchery, hang from rafts that float in the stream, usually near a lake outlet (SEP 1993). Alternatively, incubation boxes may be set into a streambank and have stream water piped to them. The "Bams box" is the major incubation box developed by SEP (Bams 1982). The boxes protect the eggs from floods and predators until the fry emerge and enter the stream.

Natural egg to fry survival is an average of about 15%. Enhancement increases survival to 80% for an incubation box and to about 95% in hatchery trays (DFO 1976). But survival in the incubation boxes can be highly variable due to the settlement of fine sediment in the gravel boxes.

6.5.2 Human controlled rearing - Feeding

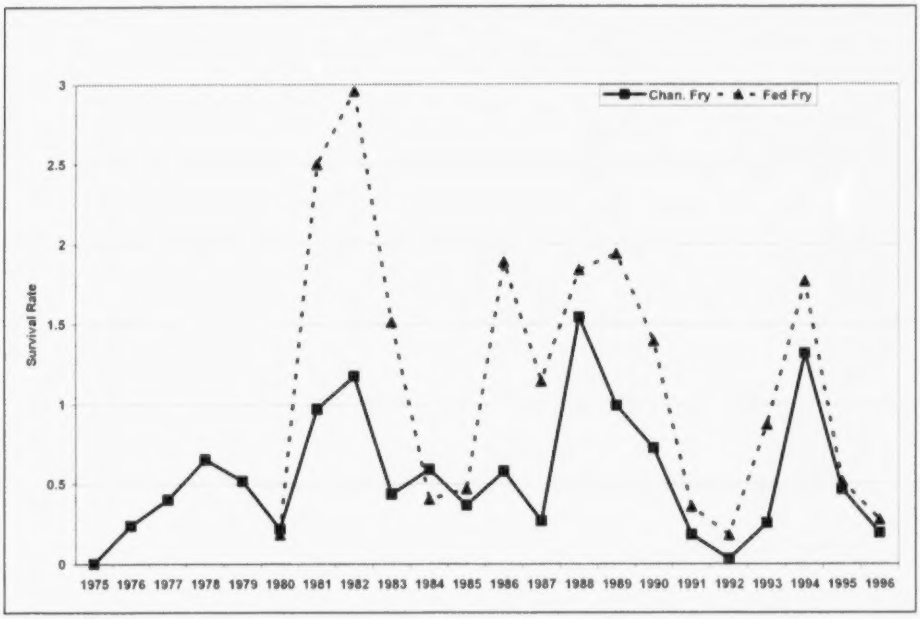
Human controlled rearing involves feeding salmon and protecting them from predators to increase the number and size of juveniles produced. Usually the salmon are captive in freshwater ponds, lakes or sea pens. In some cases, there has been supplemental feeding of non-captive fish in streams. In B.C. such feeding is usually done in conjunction with some form of incubation enhancement. The feeding results in increased size of juveniles which helps them to avoid some predators and have better survival on average after they are released (SEP 1993).

A typical example of this technique is ponds where fry are fed in projects run by public groups. The number of such projects has decreased during the past decade.

The Biostandards of SEP suggest that survival rates from feeding are 50-60% at the fry-to-smolt stage, 2.3% for the fry-to-adult stage, 1 to 10% at the smolt-to-adult stage, and .1 to 1% for the all stages, egg-to-adult (DFO 1976). Figure 16 shows the difference in chum survival from release to adult of unfed channel fry and fed hatchery fry in the Georgia Strait Vancouver Island area. Data are from the SEP database. The greater survival of the fed fry is attributed to feeding and larger size at release. This gives them possible competition and predator avoidance advantages. It is not clear why the difference in survival between fed and unfed fish varies so much.

Figure 16: Release-to-adult survival of fed chum fry compared to unfed chum fry in the Georgia Strait area.

Source of data: SEP database



6.6 Human controlled spawning and rearing combined - Hatcheries

6.6.1 The technology and how it works

Human controlled spawning, incubation and/or rearing occur in hatcheries. In hatcheries, eggs are taken from female salmon, fertilized with milt from males and incubated under carefully controlled conditions. In the clean, free-flowing water of the hatchery, protected from movement and light, the survival rate for the egg-to-fry life stage is greatly increased. Juveniles are reared at the hatchery in containers and then released to migrate to the ocean. Some may be seapen-reared before release.

There are a number of different mixes of enhancement methods used in different hatcheries. Conventional hatcheries typically use bulk incubators and ponds or raceways for rearing. Traditional Japanese-style hatcheries that incubated chum eggs in gravel (as opposed to in trays) have been modified and blended with conventional technology for use with all salmon species. Strategies depend on the species. Chum and pink salmon are released either unfed after emergence from channels or incubation boxes, or as fed fry from hatcheries or sea pens after one month of feeding. Coho are released as fry, either at emergence or after three to five months of rearing, or as smolts after one year of rearing. The majority of sockeye are released as unfed fry, although a small number are hatchery incubated and short-term reared. In the case of chinook, coastal stocks are released after three to four months of rearing, while Interior stocks are frequently reared for one year to the yearling stage.

"Segregated" hatchery programs are designed to minimize the number of artificially propagated fish spawning in natural habitats or interacting with natural populations of that species. In DFO, these are programs where populations have been transplanted to locations where the species did not exist at all, or did not return to spawn (e.g. chinook on the Capilano River were transplanted from the Big Qualicum River, then Harrison River). Transferred fish do not have an opportunity to interact with naturally spawning populations of that species in the receiving stream, as most of the hatchery fish that survive to adult come back to the hatchery where they are used again for broodstock (source of eggs and milt). (These are also defined as "closed" or segregated breeding stocks.)

Most hatcheries in B.C. are "integrated" hatcheries that aim to have returning adults reproductively integrated in the wild population, which was the source of the broodstock. It is assumed that this strategy does not exert significant selective pressures on the enhanced fish. There are also satellite integrated enhancement strategies, in which eggs are taken from other populations in the vicinity of the hatchery, incubated, reared and then planted back into the donor areas (e.g. Kitimat and Bella Coola hatcheries). Enhanced fish are released as juveniles to reside in the ocean, and then return to spawn in natural habitats in the systems from which they originated. Thus, the hatchery does not create a separate hatchery stock but rather strives to enhance all populations in the area.

Much of the DFO hatchery program follows an integrated production strategy for Pacific salmon. As a consequence, the program has from the outset endeavored to maintain the demographic and genetic characteristics of returning cultured salmon to be as similar to the parent wild stock as possible, by using local stocks.

Another strategy is that of "captive broodstocks." For threatened or endangered stocks, salmon may be bred and reared in captivity to mature adults which are then bred to produce more eggs and fry, which are released to the natural environment. This approach significantly reduces the high natural mortality from smolt to adult, thereby increasing the re-building rate of the population.

The above comments are intended to describe a range of hatchery programs. However, individual facilities may differ to some extent, and programs may change over time.

6.6.2 Number, size and location of enhancements

Table 5 shows the numbers of hatcheries by species and production area. Most hatcheries are in the south in the Georgia Basin area.

Table 5: Numbers of hatcheries by species and production area in B.C. and Yukon.

The production areas from north to south are: Yukon = Yukon Territory; TRANS = transboundary rivers in Northern B.C.; QCI = Queen Charlotte Islands; NASS = Nass watershed; SKNA = Skeena watershed; NCST = North Coast; CCST = Central Coast; RI = Rivers Inlet; JNST = Johnstone Strait; NWVI = North West Vancouver Island; GSMN = Georgia Strait northern mainland; GSMS = Georgia Strait mainland south; GSVI = Georgia Strait Vancouver Island; SWVI = South West Vancouver Island; LWFR = lower Fraser; TOMM = Thompson River mainstem; TOMF = Thompson Forks (North and South Thompson); UPFR = upper Fraser. (Source of data: SEP data base)

Area	Chinook	Chum	Coho	Pink	Sockeye	Steelhead	Cutthroat
YUKN	1						
TRANS	1						
QCI	2	3	7				
NASS	1	1					
SKNA	3		6				
NCST	1		2				
CCST	2	4	6	1	3	1	1
RIVI							

Area	Chinook	Chum	Coho	Pink	Sockeye	Steelhead	Cutthroat
JNST	6	5	12	3	1	2	
NWVI	6	2	5			2	
GSVI	8	12	17	7		2	2
GSMN	7	17	18	2	1	2	2
GSMS	2	1	2			1	1
SWVI	8	5	9		2		
LWFR	8	11	16	4	1	4	2
TOMM	1	1					
TOMF	2	2			1		
UPFR	3						
TOTAL	62	64	100	17	9	14	8
Releases(M)	46.84	95.33	17.81	19.27	10.40	1.00	0.11

Most hatcheries produce more than a single species. The total number of hatcheries (i.e., individual facilities) in B.C. and Yukon is more than 120, ranging in size from small public involvement to large production facilities. They range in size from releases of one or two thousand to almost 35,000,000 chums from the Nitinat hatchery. Most hatcheries are located in the Georgia Basin area. This area is also most subject to industrial and urban development pressures, the most people, and the highest demand for sport fisheries.

Figures 6, 7, 8 and 9, and Tables 4 and 5 in the Appendix of Data illustrate hatcheries by area and species and by size and species. Hatchery size varies by species. Chinook hatcheries range in size from 2,000 to 7,680,000 releases. The most frequent coho hatchery size is 100,000 to 200,000 releases, with the range from 10,000 to 1,950,000. Hatchery releases are smaller for steelhead (1,000 to 225,000) and cutthroat (2,000 to 50,000). These are recent release numbers. Many of these facilities have reduced releases due to funding cut-backs, so that these numbers may not be typical of the hatcheries in the past.

The shorter hatchery rearing stage of chum, pink and sockeye means that hatchery releases tend to be larger than for chinook, coho, steelhead and cutthroat. Average number of hatchery releases per hatchery is about 3 million for chums, 1.2 million for pinks, and 2.5 million for sockeye. The Pitt River (now at Inch), Shuswap, Alert Bay, Snootli, Bella Bella, and Klemtu hatcheries all produce sockeye.

Average releases by species also vary across hatcheries in an area. Figures 10 and 11 and Table 6 in the Appendix of Data set out average releases by area by species. In total, average releases are highest in the Georgia Basin area.

6.6.3 Associated survival rates

Survival rates from enhancement at hatcheries are high, with 95% levels at the egg-to-fry stage, 75-80% at the fry-to-smolt stage and 1.5-15% at the smolt-to-adult stage (DFO 1976). The smolt-to-adult stage survivals that were in the 5-15% range with the 1970s ocean conditions dropped to less than 1% under recent condition. These egg to smolt survival rates were as much as five times higher than wild stocks would be expected to exhibit. Smolt-to-adult survival rates are very different between species.

Before 1977 smolt-to-adult survivals were in the 3 to 5% range for chinook and 15 to 20% for coho. After 1977 survivals decreased to about 1.5 to 0.5% for chinook and 8 to 2% for coho. The change may be related to a regime shift in 1977.

6.6.4 Overview of hatcheries and their effects

- Human controlled spawning and rearing combines human controlled spawning, incubation and rearing in hatcheries (i.e., taking salmon eggs, fertilizing them, and incubating them in an artificial environment, then feeding the juvenile salmon and protecting them from predators).
- There is a range of hatchery sizes from small to very large.
- All species are enhanced in hatcheries, with the main species being chinook, coho, steelhead, cutthroat and chums.
- Over-harvesting of wild salmon in mixed stock fisheries with relatively large numbers of enhanced stocks from hatcheries is a serious risk.
- Hatchery enhancement can have negative genetic effects on wild salmon through domestication, outbreeding depression and inbreeding depression. The extent of these impacts is particularly difficult to quantify.
- Competition between hatchery and wild salmon for spawning, rearing and particularly ocean habitat and food is also a serious risk.
- Production can affect competition and predation in the watershed, estuary and coastal areas. Predation of wild fish by predators attracted by hatchery stocks is a risk, as is predation on wild fish by hatchery fish.
- Health risks through transfer of disease from enhanced to wild fish is a possibility.

6.7 Species focus of various enhancement methods

Most enhancement methods could be applied to any species. However, the nature and life cycle of each species determines what type of enhancement is most appropriate. For example, most stream rearing species such as steelhead, cutthroat, chinook and coho are produced in hatcheries, and lake rearing sockeye are produced in spawning channels. Most chums are produced in spawning channels and hatcheries. Most pinks are produced using available space in hatcheries. Hatcheries and managed spawning channels account for by far the most salmon enhanced production in B.C.Table 6 shows which species each type of enhancement applies to.

Table 6: Enhancement methods by species.

The 'Y' indicates "YES' a technology is applicable to a species.

Enhancement Technology	Chinook	Chum	Coho	Pink	Sockeye	Steelhead	Cutthroat
Increased Natural Habitat							
Obstruction Removal	Y	Y	Y	Y	Y	Y	Y
Fishway	Y	Y	Y	Y	Y	Y	Y
Improved Natural Habitat							
Spawning Habitat	Y	Y	Y	Y	Y	Y	Y
Rearing Habitat	Y		Y			Y	Y

Flow Control	Y	Y	Y	Y	Y	Y	Y
Temperature Control	Y	Y	Y	Y	Y	Y	Y
Artificial Habitat							
Spawning Channel		Y		Y	Y		
Rearing Channel	Y		Y			Y	Y
Stream Enrichment	Y		Y			Y	Y
Lake Enrichment					Y		
Human Controlled Spawn/Incub.	Y	Y	Y	Y	Y	Y	Y
Human Controlled Rearing							
Ponds/Channels	Y		Y			Y	Y
Lake Pens	Y						
Sea Pens		Y					
Hatcheries	Y	Y	Y	Y	Y	Y	Y

Y = YES

Table 7 shows the proportion of production contributed by each type of enhancement for coho salmon, demonstrating that individual species are enhanced by various methods.

Table 7: Percent contribution of enhancement types.

Source of data: SEP data base

Enhance. Type	**Chinook**	**Chum**	**Coho**	**Pink**	**Sockeye**	**Steelhead**	**Cutthroat**
Hatcheries	85.3%	32.7%	85.5%	59.3%	4.5%	98.5%	81.5%
Channels		0.9%	0.4%	2.8%	88.8%		
Hat/Chan Comb.	11.4%	31.5%	7.2%			1.5%	18.5%
Sea Pens	0.6%		0.2%				
Class Incubators	0.1%		0.7%				
Habitat Improve.	2.7%	34.8%	6.0%	37.8%	4.6%		
Lake Enrichment					2.1%		

7. INTERACTIONS BETWEEN ENHANCED AND WILD SALMON

This section describes the major issues related to interactions between enhanced fish and wild fish, by interaction type. The vast majority of work associated with interactions has related to hatchery types of enhancement because of their long history and magnitude of production. For each of six types of interaction the possible negative effects of the interaction on wild salmon are explained, counter-arguments and possible positive effects are summarized, and relevant experience and examples are outlined. Measures to counteract potentially negative interactions are reviewed in Section 8.2.

The six interactions explored here are frequently clustered into three categories:

- genetic;
- ecological (competition, predation, fish health and habitat); and
- fisheries (mixed stock fisheries).

7.1 Mixed stock fisheries interactions

7.1.1 Possible negative effects

Negative effects of mixed stock fishery interactions are explained here under two themes: overharvest of wild salmon in stocks mixed with enhanced salmon, and presence of enhanced salmon masking declines in wild salmon stocks.

Overharvest of wild salmon in stocks mixed with enhanced salmon

Managing fisheries with stocks of differing productivity has always been challenging, and even in the absence of enhancement, mixed stock fisheries would continue to pose management difficulties. However, major enhancement projects in the form of hatcheries and spawning channels have substantially exacerbated the difficulties in some areas. In areas that have enhanced stocks mixed with wild stocks, enhanced production can lead to unsustainable fishing mortality rates for wild salmon. The situation leading to over-harvesting of wild stocks is as follows: harvest rates are set at levels related to total abundance of fish in an area; enhancement has raised that abundance; enhanced stocks are co-migrating with wild stocks; and wild salmon are caught mixed in with salmon from enhancement. The enhanced stocks may withstand the harvesting pressure or even be under-harvested, while less productive, co-migrating wild stocks are over-harvested.

This mixed stock fishery effect operates like a ratchet that keeps tightening the pressure on the wild stock, continually reducing the numbers of spawners. This is probably the main way in which hatcheries have resulted in the displacement of wild salmon.

The potential fisheries interactions between an enhanced population and other populations are broader than just in the watershed. Natural populations could be over-harvested in any fishery in which enhanced populations constitute a significant portion (from the same watershed as the enhancement facilities and from other watersheds). For chinooks, the fishing areas generally extend north from the home watershed through the coast of Alaska.

Factors in the fisheries that can aggravate the mixed stock fishery impact include:

- The level of impact of enhancement is related to the survival rate and number of enhanced fish relative to wild populations. The larger the differences in the production rates between enhanced and wild fish (in the direction that makes enhanced fish outnumber wild fish), the more the wild stock is likely to be over-harvested in mixed stock fisheries.

- Related to the above factor, in years when wild production is down because of freshwater habitat factors (while enhancement protects fish from much of this natural variation in survival), wild populations may be driven down further by mixed stock fisheries. Also, in those years the percent of naturally spawning fish that were produced through enhancement programs tend to be highest.
- Irrespective of regulation, fishing effort is naturally drawn to areas with a relative abundance of fish, whether wild or enhanced, so that fishing pressure on the populations in those areas increases.
- In some cases, as the salmon migrate back to their home stream, over-harvesting can be aggravated by the same populations being fished sequentially in a number of fisheries.
- Under-harvest/over-escapement of enhanced populations might increase straying and excessive populations could increase the genetic and ecological risks.

When selective harvesting is effective, it benefits wild stocks through reduced harvest rates and provides fishing opportunities. However, in fisheries "It is difficult, impossible perhaps in practice, to harvest abundant hatchery salmon and concurrently protect scarce wild salmon." (Lackey 2003 p.51, on U.S. experience) A recent approach to selective fishing is to mark hatchery-raised salmon by removing the adipose fin so that if an unmarked salmon is caught it is assumed to be wild and must be released. But this technique, which is used for hook and line fisheries, still inflicts mortality on wild salmon if fishermen do not comply with the requirement to release unmarked fishor if fish die after being hooked, caught and released. If selective fisheries do not take all of the harvestable enhanced production, it can be harvested in ESSR (Escapement Surplus to Spawning Requirements) fisheries at or near an enhancement facility.

On the other hand, recent research by DFO suggests that selective harvesting can be successful in reducing harvest rates on specific salmon stocks. Other measures that reduce the impacts of mixed stock fishing on wild salmon have also had some success. These are summarized in Section 8.2.

Presence of enhanced salmon masking declines in wild salmon stocks

Fisheries management, for many years, allowed fisheries to respond to the total abundance of salmon and did not fully protect the wild populations mixed with the enhanced production. In Canada, this has been a long-term issue as the huge hatchery releases from the United States have mixed with wild salmon and further increased the apparent abundance of salmon in Canadian waters. As fishery mortality increases with fishing effort and abundance, the cumulative effect over all fisheries is to over-harvest the less productive, wild populations. This problem had been recognized for many years before actions were taken to more appropriately manage fishing rates for the natural populations.

Enhancement can mask the decline of wild stocks by the presence of relatively abundant hatchery-bred salmon, even in natural habitat (Bottom 1997 in Lackey 2003 p.51). As hatchery fish have typically not been marked they cannot easily be distinguished from wild salmon. Effective monitoring of the natural populations would require assessment of spawning escapement trends in these natural populations, estimates of the fishing impacts on these populations, and monitoring of numbers of hatchery fish in the catch and spawning escapement.

The outcome is that hatchery releases can maintain levels of total catch, overshadow declines in wild stock status and, in turn, slow the recognition of the need to implement harvest reductions to enable recovery of wild stocks. As well, a high rate of straying of unmarked spawners of cultured origin to an unenhanced system may mask declining escapements of wild fish.

7.1.2 Counter-arguments and/or possible positive effects

Some counter-arguments to the negative interactions described above are:

- Likelihood of mixed harvest pressure differs by species and their dominant fishery type. Sockeye, chum and pink are mainly harvested in commercial fisheries. These fisheries are actively managed and are somewhat stock selective by time and area fishing restrictions as compared to sport fisheries. However, minor stocks, such as small sockeye populations, are still not protected by these commercial fishery management measures. In particular, stock-specific, terminal fisheries have the best potential for targeting enhanced stocks.

- Other enhancement techniques could be used to raise the numbers of wild salmon, reducing the proportionate difference in mixed stocks. For example, "... fertilization may be a more useful tool to manipulate the cyclic patterns in abundance by improving marine survival of weaker lines, compared with the alternative strategy of trying to reduce harvest rates, which is often difficult to do in mixed-stock fisheries." (Bradford et al. 2000 p.670)

- Fishing effort on enhanced fish distract effort from wild fish if fishing gear or available time to fish limits the fishing pressure: "In such (rare) cases, increased abundance of hatchery fish can essentially fill the gear/time, so that the effective effort to which wild fish are at risk is reduced." (Walters and Martell, in press, p.8 of ms.)

- Abundant enhanced stocks in areas away from wild stocks may relieve fishing pressure on the wild stocks, as fishing effort is attracted away from areas where wild fish are concentrated.

- The mainly small project size and semi-natural habitat of the individual chinook and coho channel enhancement projects might suggest that they would result in minimal mixed stock fisheries problems. Because these habitat improvements increase natural survival rates, they could help to reduce the differences in productivity and mixed stock fisheries problems.

- Abundant enhanced stocks could buffer wild populations under certain management strategies. For example, the 1985 Pacific Salmon Treaty set chinook catch limits in coastal fisheries. If the number of hatchery fish increased in a fishing area, then less wild fish could be caught under the fixed catch limit. The assumption underlying this strategy was that survival rates were large enough that harvest rates under the catch limits would effectively be reduced.

Several mitigative measures that can be taken to reduce the negative impacts of mixed stock fisheries are discussed in Section 8.2. In contrast to the U.S. experience reported by Lackey (2003), experience in B.C. has demonstrated that high levels of species selectivity are possible by modifying fishing gear and methods and stock selectivity by time and area restrictions:

> *"In three years of experiments, demonstration projects, and workshops, major progress has been made in understanding the mortality of coho bycatch in various areas on the coast. Major progress has been made in developing ways to reduce mortality and stress in coho bycatch. Increased spawner abundance in many areas has resulted from the selective fishing actions taken. Equally important, good progress has been made on the selective harvesting of target stocks." (Wood and Fearon 2001)*

Selective fishing initiatives have demonstrated that:

- When required to, gill netting, seining, and trolling can live release non-target species with very low mortality rates. For example, day-only fisheries have significantly increase coho avoidance.
- When commercial fishermen know that fisheries will be closed unless they all release the non-target fish alive, fishermen comply, rather than losing fishing opportunities.
- The percent of fish that die after being hooked, caught and released has been reduced by changing to barbless hooks and hauling lines with single fish instead of waiting for multiple fish. Lure and hook size is also species and size selective.
- An integrated strategy of selective harvesting is making it easier to enforce gear and operational requirements.

In short, there have been progressive changes to reduce mixed stock fisheries. The mixed stock fisheries problems are not solved but have been significantly reduced from what they were even a few years ago.

7.1.3 Experience and examples

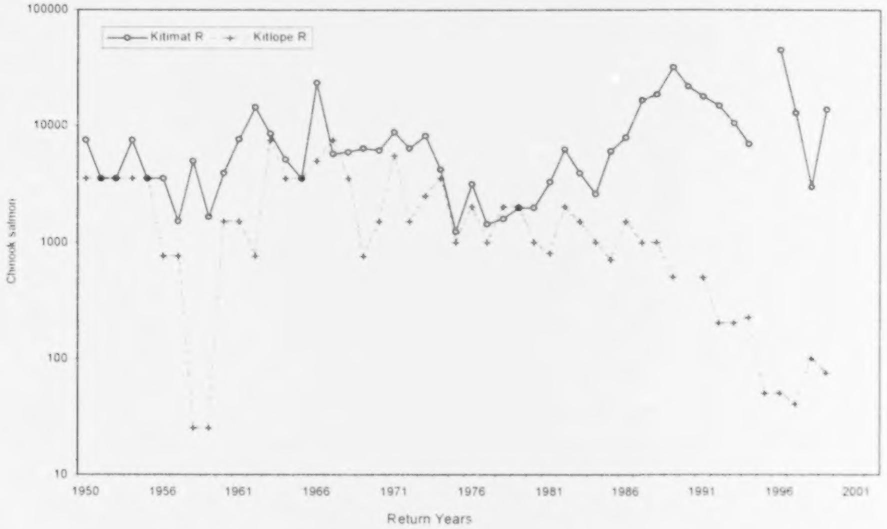
Mixed-stock fishery impacts are typically considered to result from excessive levels of fishing that develop in the response to large abundances of salmon (of mixed hatchery and natural origins) but are not sustainable by Pacific salmon produced in natural environments. The first four examples below illustrate this type of effect.

Large abundances in fishing areas may also mask the true condition of natural salmon populations; i.e., indicators of fishing success may indicate large abundances of salmon but hide the declining production from some natural populations. The fifth example in this section, focused on Thompson River coho salmon, illustrates this additional risk related to mixed-stock fishing and inadequate monitoring programs.

Kitimat and Kitlope chinook

Starting late in the 1970s the Kitimat hatchery increased chinook releases by a factor of 10. This supported more intensive fisheries and resulted in increased harvest rates in mixed stock fisheries on both enhanced Kitimat stocks and wild Kitlope stocks. As a result the abundance of Kitlope chinook spawners decreased by more than a factor of 10. The increase in Kitimat releases and decrease in Kitlope stocks are shown in Figure 17. A more detailed analysis of this example is forthcoming in a report from the Pacific Fisheries Resource Conservation Council.

Figure 17: Chinook escapement (log scale) of Kitimat and Kitlope chinook stocks



Georgia Basin/Strait of Georgia Coho

Declining wild coho salmon stocks in the Strait of Georgia have been a major problem, likely related in part to mixed stock fisheries involving hatchery and other enhanced coho production. A 1992 plan for rebuilding Georgia Strait coho described the problem in part as follows: recreational and commercial catch of wild coho dwindled by an average of about 66,000 fish per year between 1976 and 1989 but was masked by increased catches of hatchery coho (Coho Steering Committee 1992 p.7).

Over 200 enhancement projects, including ten major hatcheries, have attempted to increase coho production in the Strait of Georgia and Fraser River areas since the early 1980s (PFRCC 2002 p.44). The many enhancements feeding into the Georgia Strait area collectively produce large numbers of enhanced fish that support intense fisheries. This led to the Strait of Georgia coho populations being fished for several years at unsustainably high harvest rates due to fishing effort based largely on hatchery coho (Perry and Kling 1993). The composite mixed stock fishery effect of enhanced coho in Georgia Strait put the exploitation rate on the coho at more than 10% above the estimated sustainable rate. Coho spawning escapements continued to decline despite large investments in enhancement, to the point that fisheries were eventually closed (PFRCC 2002 p.45).

Babine Channels and Skeena River Sockeye

The interactions between Babine channel production and other salmon populations in the Skeena system are well described in an up-coming report from the Pacific Fisheries Resource Conservation Council.

The Babine Lake Development Project was implemented between 1962 and 1971 in the Skeena River basin. The project consists of two spawning channels on the Fulton River, one at Pinkut Creek, and associated river flow control works. The channels were expected to supplement natural sockeye production by an additional 100 million fry in the main basin of Babine Lake and ultimately to increase adult returns and commercial catch (West and Mason 1987). By 1987, adult returns of Fulton and Pinkut origin had increased nearly four-fold, indicating a successful enhancement project (West and Mason 1987). In terms of the interactions between the salmon produced by the project with wild salmon in the Skeena River system, the picture is more complicated. Virtually all of the salmonid species are produced in the system, including many sockeye stocks, and many of them are subject to harvesting in mixed stock fisheries.

The Skeena sockeye run is composed of over 50 spawning locations, with two of the stocks from the enhancement project producing most of the run (Sprout and Kadowaki 1987). All Skeena species pass through the terminal fishing area between June and September. The sockeye pass through from early June to mid-August in six stock groups. For example, the non-Babine early Skeena in June, the Babine Lake tributaries in late June and July, the enhanced Pinkut in late June to mid-July, and the late Skeena in August. Regarding the other salmonids: chinook peak before directed sockeye fisheries; pink salmon pass through from mid-July to early September; upper Skeena coho and steelhead pass through from late June through August (coinciding more strongly with pinks than sockeye); finally, late run coho and steelhead not intercepted in fishery (DFO 1992).

Timing overlaps in the harvest area between enhanced and unenhanced sockeye and all the other species make it difficult to achieve optimal management of each species (Sprout and Kadowaki 1987 p.385). This difficulty is aggravated by the differences in productivity and life history characteristics between the stocks in the Skeena system. The largest and most productive is Babine sockeye. Even before enhancement this was the most productive sockeye in the Skeena system. After major, large-scale spawning channels were added, the productivity and production increased and aggravated existing mixed stock fisheries problems. Small populations of wild sockeye and populations of steelhead and coho in the Skeena watershed were over-fished for several years because of fisheries directed upon enhanced sockeye runs to the Babine system in the Upper Skeena watershed. In 1987 Sprout and Kadowaki observed that "With the exception of the earliest and latest stocks, and given the constraints on fishing techniques and locations, fishery managers have little flexibility in manipulating the timing of fisheries to avoid harvesting non-target stocks." (p.389)

In response to the mixed fishery problems, fisheries management was changed to be selective for channel production. From the 1970s to the 1990s, increasingly restrictive management actions were taken to protect less productive populations of steelhead, coho and chinook (while exploitation rates in the Alaskan fishery rose) (DFO 1999a p.3). A 1992 DFO paper reported that:

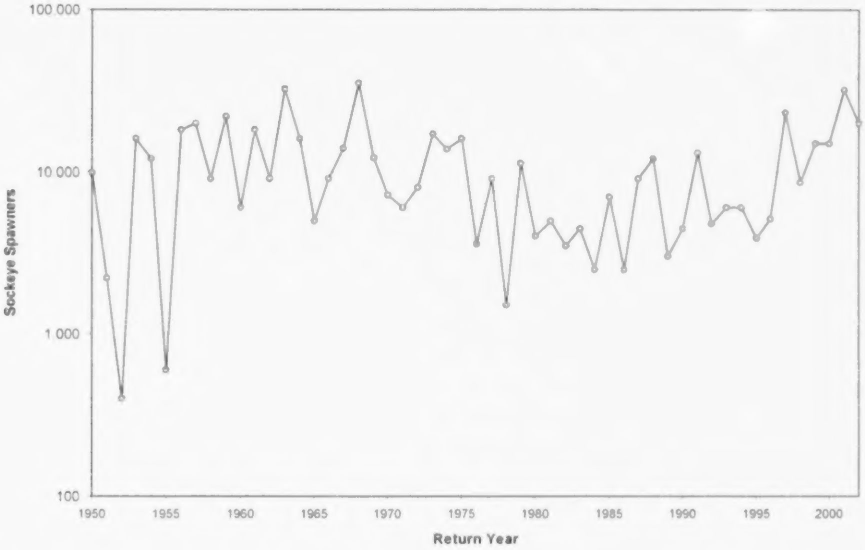
1. Rebuilding of the Skeena sockeye fishery using a combination of harvest management and enhancement has been very successful.
2. Harvest rates on sockeye in the terminal commercial fishery have declined since enhancement came on-line. This has resulted in some positive benefits for wild steelhead, coho, chinook and sockeye, even though sockeye catches are now at record levels. Wild Skeena chinook and pink stocks are rebuilding, while the status of wild coho, steelhead and sockeye stocks is variable.
3. The conservative harvest policy for Babine sockeye results in a substantial surplus, estimated in the range of 300,000-600,000 fish annually. Increased harvest in the Babine system without wild stock interaction is feasible and anticipated in the near future.

In the 1990s, harvest rates on Skeena sockeye rose, in part reflecting the selective harvesting of enhanced sockeye salmon in-river and in terminal ocean areas. In 1999 the enhanced Fulton and Pinkut runs were reported to account for about 90% of sockeye recruitment to the main basin of Babine Lake, and there were surplus returns of these runs because harvesting levels are set to prevent over-harvesting of less productive populations (DFO 1999b p.4). At the same time, escapements to wild runs within Babine Lake whose run timing is either earlier or later than the enhanced Fulton and Pinkut runs were not statistically different from pre-enhancement levels.

Recently, there has been increased selective harvesting to provide increased protection to the non-enhanced Upper Skeena coho and Nanika River sockeye populations (PFRCC Annual Report 2000-2001).

Data on the wild Morrison River run indicate some negative effects from enhancement from the Babine channels. These wild fish co-migrate with the fish from the spawning channels and are thus harvested together. While decreased harvest rates have recently increased abundance of Morrison spawners, escapements to the wild Morrison River run remained below pre-enhancement levels (DFO 1999a p.3). (See Figure 18).

Figure 18: The number of sockeye spawners in Morrison Creek and Lake in the Babine system from 1950 to 2002.



These results appear to confirm the necessity of selective harvesting to protect wild stocks from over-harvesting when mixed with enhanced stocks, and to confirm the difficulty of achieving this when stocks are mixed in time and place.

Weaver Creek Channel and Cultus Lake Sockeye

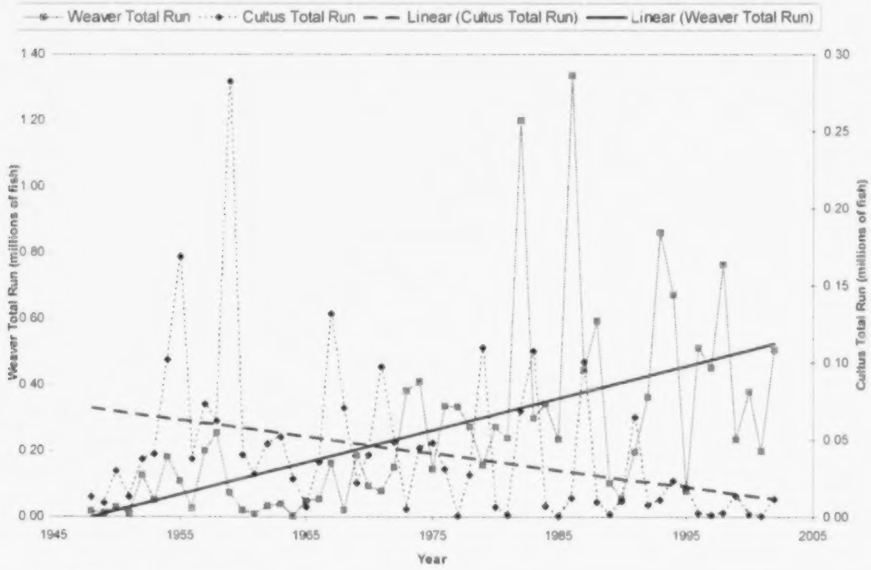
In May 2003, COSEWIC recommended listing Cultus Lake sockeye salmon as Endangered. COSEWIC (2003) concluded that the depressed condition of this stock resulted from over-exploitation by fisheries, recent increases in the level of pre-spawning mortality associated with the early adult migration in late-run Fraser sockeye, and reductions in marine survival rates during the mid-1990s. Cultus Lake sockeye are a small component of the late-run stock aggregate of Fraser sockeye salmon. Fisheries have typically been managed on the abundance of the aggregate return. This return is dominated by Adams River sockeye in two years of the four-year cycle and by the enhanced Weaver Creek sockeye in the other two years. Schubert et al. (2002) reported that on the 1998 sub-dominant and 1999 dominant cycles, the fisheries are managed to meet harvest and escapement objectives for Adams River sockeye with averaged harvest rates of 72% and 77%, respectively. On the 2000 and 2001 off-cycles (i.e., lower abundances), the fisheries are actively managed for Weaver sockeye, where the wild stock has been augmented with enhanced production since the spawning channel began operation in 1965. Harvest rates on these latter cycles increased from between 57 and 65% (average by respective cycle) prior to enhancement, to between 81 and 83% per cycle after enhancement (Schubert et al. 2002 p.28).

"The escapement of Cultus sockeye adults declined by 51% over the last three generations, a continuation of a trend that began following the construction of the Weaver Creek spawning channel in the late 1960's." (Schubert et al. 2002 p.ii)

Harvesting the enhanced Weaver Creek stock resulted in higher exploitation rates than the wild Cultus Lake stock could sustain, and the Cultus Lake stock abundance declined to very low levels. In the late 1990s, the exploitation rates were reduced in an attempt to rebuild the Cultus Lake stock. Figure 19 illustrates these trends.

Figure 19: Increases in exploitation rate on Cultus Lake sockeye as Weaver Creek sockeye channel stock developed, and associated decline of the Cultus Lake stock

Source: The Pacific Salmon Commission's small database for Pacific Sockeye



Schubert et al. explain how policies aiming to realize the full benefits of the increased production at Weaver Creek led to this over-exploitation of Cultus Lake sockeye:

> *"The Department's management policy establishes fishery objectives and escapement targets for the dominant stocks in the group (either Weaver or Adams), resulting in sub-optimal exploitation rates on other stocks such as Cultus. The policy acknowledges that the less productive stocks may not achieve their productive capacity but assumes that they will stabilize at lower levels. We conclude that this assumption is likely invalid for Cultus sockeye because exploitation rates at the high end of the historic range have caused sustained declines in the size of the population." (Schubert et al. 2002 p.33)*

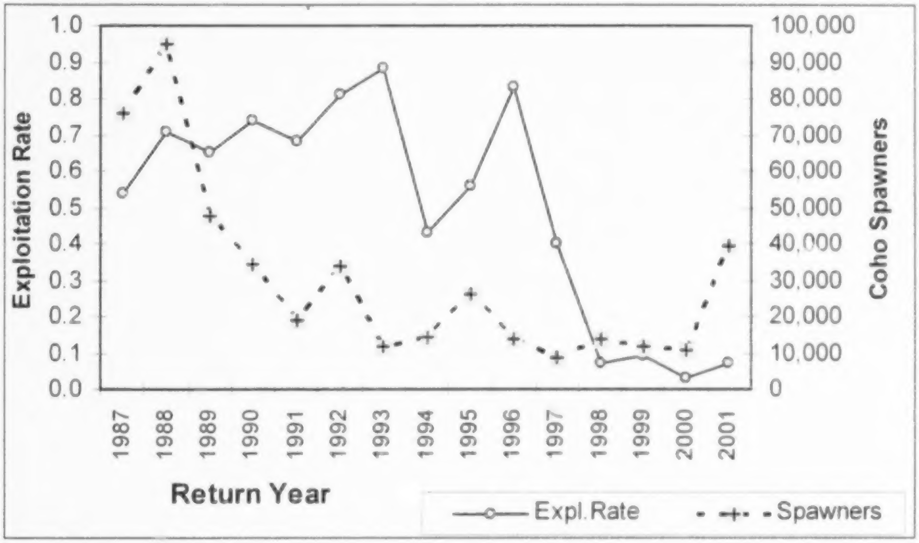
In terms of just the interactions between Weaver Creek (enhanced) and Cultus sockeye stocks, it is true that the mixed-stock fishing interactions primarily occur in two of the four years; although the Weaver Creek spawning channels do contribute production to each year.

Thompson River coho salmon

In May 2002, coho salmon returning to the interior Fraser tributary, the Thompson River, became the first Pacific salmon stock listed by the Committee on the Status of Endangered Wildlife in

Canada (COSEWIC 2002). The stock was assessed to be at serious risk of extinction "due to changes in freshwater and marine habitats and to overexploitation." Coho salmon from this region are caught in fisheries throughout southern B.C. and Washington State and, since the mid-1980s, have been monitored by marking fish released from the Salmonid Enhancement Program in the Thompson tributaries. However, in the mid-1990s serious declines in the spawning escapements to the natural populations in the Thompson River were detected and subsequently resulted in the closure of coho fisheries in southern B.C., and ultimately to the listing of this coho salmon stock under the Species at Risk Act (Figure 20).

Figure 20: Thompson River coho salmon spawners and exploitation rate from 1987 to 2001 return years



Given the monitoring of this stock, how could this situation develop? In retrospect the situation exemplifies the issue of operating fisheries on mixtures of many stocks and the danger of masking the status of any one stock in the fishery. Data presented in Irvine (2002) clearly demonstrates a lag in reducing fishing pressures compared to the declines in spawning escapements of Thompson coho salmon (Figure 20 was developed from the data in Table 1 of Irvine 2002). Exploitation rate is a measure of fishing pressures on a stock. For example, a 70% exploitation rate means that 7 of every 10 adult coho produced were killed in fisheries. The number of spawners in Figure 20 is the estimated number of coho salmon that returned to the South and North Thompson rivers in each of these years. It is apparent that the numbers of spawners had declined substantially by the early 1990s, but that major reductions in fishing pressures did not occur until 1997. One reason for inaction was that the Thompson coho stock constituted a very small portion of the ocean abundance of coho. Catches in ocean fisheries continued to be large but management was not responsive to the reductions in one natural coho stock.

Bradford (1998) has shown that earlier reductions in fishing impacts could have reduced the risk of extinction of the Thompson stock of coho salmon. A full discussion of the stock status of Thompson coho salmon and data used in these assessments has been presented by Irvine et al. (2001). This example is clearly *not only* an impact of hatchery production mixing with natural coho but also reflects the need for careful monitoring of the natural stocks mixed with large abundances of hatchery-produced coho salmon, both in fishing areas and in spawning populations.

7.2 Genetic interactions

7.2.1 Possible negative effects

If fish interact on the spawning ground but do not produce any offspring, there may be ecological or demographic effects but there would not be a genetic effect in future generations. This interaction or gene flow between the hatchery and wild populations is one of several factors within the hatchery and the natural environment affecting potential genetic interactions between a hatchery population and a local wild salmon population. Other basic issues relate to the source of the hatchery fish (i.e., the initial parents that formed the hatchery population) and changes in the hatchery fish population due to inadvertent and directed causes. Key factors are:

- Hatchery populations may be developed from local or non-local parents and have, at times, been developed from a very small number of parents (most intensive culture systems random mate parents and do not allow sexual selection between parents; spawning channels are an exception to this).
- Changes within a hatchery may simply be the response to the hatchery environment (i.e., inadvertent change or domestication) or may be deliberate selection for a trait such as run-timing.
- Interactions or mixing of hatchery and wild fish requires inter-mating and survival of the offspring. In total, this is genetic exchange or gene flow between these spawning groups and is a required condition for genetic effects.

Genetic risks are of heightened concern for Pacific salmon because of their unique homing to natal streams and their adaptations to local environmental conditions. It is commonly accepted that natural selection has worked to produce near-optimal distributions of genetically determined traits. For example, the distribution of spawning time for an undisturbed population of salmon provides the best chances of survival for that population (Reisenbichler 1996 p.224). The "stock concept" of Pacific salmon has been fundamental to salmon management for decades and is premised upon the adaptation of localized spawning populations to their local environmental conditions (Ricker 1972, Taylor 1991, Riddell 1993b). The diversity of these localized adaptations represents the "biological basis" for the productivity of salmon and their continued evolution as environments change over time. Diversity is important in that: it provides the most efficient use of natural habitats; it buffers the effects of environmental variability; and it promotes the sustainability of the species through time. Disruption of genetic adaptations would be expected to reduce: salmon productivity, genetic variation within populations and between populations, and their adaptability to future environmental changes.

These types of concerns are common to all hatchery programs but the degree of risk to natural populations is also related to species involved, the number of hatchery fish relative to the wild (i.e., the scale of production), and how the facility is managed. Pink and chum hatcheries, for example, typically use large numbers of adults, only rear the juveniles for short periods, and may not feed them. The numbers released would usually be less than the natural production (although there are areas of enormous hatchery releases, such as the Japanese chum programs and Prince William Sound pinks in Alaska). At the other extreme, hatcheries for spring chinook, coho, and steelhead salmon may use a limited number of parents, and may hold and rear juveniles for over a year. Their releases are frequently larger than production from local natural populations.

These concerns can be greatest for "conservation" hatcheries. The objective of a conservation hatchery is to increase the numbers of fish spawning naturally. However, the numbers of parents available to the hatchery program may be very limited. Typically then, the number of parents is small, the numbers of releases and returns are large relative to the naturally produced fish, and inter-mating of hatchery and wild fish is an objective. This combination of factors greatly increases the risk of genetic effects.

The risk associated with genetic interactions is likely the most debated of the hatchery interactions with natural populations. The issues with genetic interactions are usually not well understood, can have long-term consequences (possibly irreversible), and vary widely between enhancement programs. Hatchery releases were substantial for many years but our understanding of the genetic mechanisms is still developing and examples of impacts are known. For example, a U.S. National Research Council panel referring to the movement of hatchery strains and loss of genetic variation between populations stated:

> *"The best documented detrimental effects of hatcheries are the loss of natural patterns of genetic variability ..." (NRC 1996).*

Local adaptations in natural populations have been used to suggest that genetic changes associated with hatchery releases would simply be reversed if impacts were detected and the cause corrected or stopped. Unfortunately, there are no guarantees that this would occur. Adaptations in natural populations reflect selection processes to past environments and sequences of selective events. Any future response to an effect must respond to future environments and may not result in the same features as observed in the past. The debate concerning genetic effects is also influenced by peoples' experiences in different enhancement facilities. For example, in B.C., the issue of moving a hatchery strain to develop new hatcheries - as referred to in the NRC panel report - is seldom done, but other sources of genetic change are likely unavoidable.

Genetic differences between hatchery and wild populations have frequently been attributed to non-local sources of the original brood stock or maintaining closed hatchery populations (i.e., the hatchery brood stock has no introduction of new genetic material from non-hatchery sources). Both of these situations are recognized as genetic risks to local populations (Campton 1995 and Waples 1999). Risks associated with genetic changes in brood stock from local sources, which are being managed under more open or modern approaches, are much more uncertain and debated. However, many experts are now concluding that while the degree of genetic change can be managed, it cannot be avoided entirely (Busack and Currens 1995, Waples 1999).

A publication of the U.S. National Marine Fisheries Service provides an excellent summary of the causes of genetic change and the effect of straying from hatchery to wild populations (Grant 1997). Different enhancement practices have different effects on homing and straying. People frequently suggest that hatchery fish stray more than wild fish, but this is not necessarily true. Hatchery practices can certainly increase straying by use of non-local stocks, fish transport before release, or timing of releases. But there are hatcheries in which these practices do not apply. Waples (1999), Quinn (1993), and Grant (1997) provide good references to this issue. Further, when considering the effect of straying, it is important to understand that the effect of hatchery strays into a natural population is a function of (i) what proportion the strays are of the naturally spawning population (not the fraction of the hatchery releases that stray), (ii) whether the strays are successful in acquiring mates and spawning, and (iii) whether the strays are genetically different from the natural population. Observations of the numbers of fish straying from a hatchery cannot be equated with gene flow into the natural population, nor equated to an impact on the natural population.

The potential causes of change from the wild stock include the following phenomena.

The founder effect: The "founder effect," starting the brood stock from a small number of parents, may constitute a "bottle-neck" in the genetic variation (words in quotations are terms commonly used in the population genetics literature). A founder effect is the random or chance effect of collecting a non-representative sample (i.e., parents) of the population because of starting with a small sample. This may result in a small portion of the genetic variation from the source stock expressed in the hatchery stock (i.e., a bottleneck or limit to the variation) and to a biased collection of genetic material (e.g., only collecting a few fish from the beginning of a run-timing group). The net effect would be a loss and differences in genetic variation relative to the source wild population.

Inbreeding: "Inbreeding" is the mating together of animals related by descent or ancestry. Two individuals that are related may carry replicate genes from their ancestor. If there is a high probability of related individuals mating, then there is opportunity for deleterious recessive genes to be expressed and reduce the fitness of the offspring. The rate of inbreeding *in any population* is inversely related to the genetically effective population size (Falconer 1981). In very large populations, the genetically effective population size should be very similar to the observed or census population size. In smaller populations though, the genetically effective population size may be much smaller than the numbers of observed spawners, due to the relatedness of the parents in that small population. The concern for the genetically effective population size and inbreeding becomes significantly greater in cultured populations. For example, the genetically effective population size may be much less than the observed population size if there is a bottleneck in the number of spawners used (i.e., unequal population sizes between years some of which may have been very small), if the sex ratio in parents is not equal, if family sizes vary, and if there are over-lapping generations in the species (Waples 1990a,b). Each of these issues may exist in a salmon hatchery. In addition, the natural processes of sexual selection and mate choice do not occur and selection will be operating within this new environment (i.e., the hatchery). Each of these factors can occur in natural or cultured populations, but their cumulative effects are likely to be much greater in intensively cultured populations, such as in agriculture or fish hatcheries. The effects are cumulative and can severely depress the genetically effective population size.

As inbreeding accumulates in a population, the most striking consequence is the reduction of performance for physiological efficiency (growth) and reproductive capacity (i.e., the expression of *inbreeding depression)* (Falconer 1981). The net effect of accumulating inbreeding is two-fold: the random loss of genetic variation, and the reduced productivity of the population.

Outbreeding: "Outbreeding," the opposite of inbreeding, is the mating of unrelated individuals - usually from different populations or ancestral lines. The effects of outbreeding depend on how different the populations are and when the effects are expressed. The opposite of inbreeding depression is outbreeding enhancement or *hybrid vigor (in genetic terms "heterosis").* Typically, different populations will harbor different recessive deleterious genes, so hybrids between these populations would not be homozygous for the recessive genes. The progeny will be fitter than in either source population since the effects of the deleterious genes will be masked (see Lynch in Grant 1997).

Outbreeding depression: However, if crossing occurs between two populations adapted to different environmental conditions, differences in their genetic background may result in offspring that are not suited to either environment. Locally adapted populations are likely to possess complexes of genes within their genetic background, but the expression of these complexes may differ in mixed or crossed genetic backgrounds. The loss of fitness due to outcrossing is referred to as *outbreeding depression* and may continue to occur over several generations.

The founder effect and inbreeding are likely to occur in intensively managed broodstocks. Outbreeding and outbreeding depression are mostly likely to be expressed during inter-mating of hatchery and wild populations. They require mixing of hatchery fish with the natural population.

either intentionally or through straying of the hatchery fish. However, the impact of outbreeding and outbreeding depression would be highly dependent upon the genetic divergence between the two populations.

Two other processes are acknowledged to result in genetic change over time in the hatchery broodstocks. One is simply the loss of genetic variation due to random events (*genetic drift,*) but the second involves *selection* of genetic material within the hatchery environment. Selection may be directed or intentional, as in artificial selection practiced in agriculture. This has been conducted in some cases (e.g., to alter run timing of a stock) but is now generally discouraged in most enhancement facilities. But selection may also be inadvertent and simply be the "natural selection" that occurs in the new and novel environment of a hatchery. Other than water, there are few similarities between a typical hatchery environment and a natural environment. People have frequently argued that selection cannot be operating within a hatchery since the survival rate of juveniles is so high. However, this survival may also be a factor in the overall selection process. Waples (1999) suggests that this relaxation of selection in the cultured stock may also contribute to the domestication selection that occurs in these hatchery stocks. Waples summarizes *domestication selection* as "any change in the selection regime of a cultured population relative to that experienced by the natural populations."

When considering the source of selection in a culture population, it is critical to remember that hatchery fish are eventually released to the natural environment and those processes. The phenotypes released from a hatchery (i.e., the expression of an individual's genes and its environmental experience) will undergo heavy mortality after release. But whether this mortality involves genetic selection and how it may be conditioned on performance within the hatchery are not well documented as yet.

A short paper by Waples (1999) in the American Fisheries Society's magazine *Fisheries* provides an informative response to some "myths" about hatchery impacts.

7.2.2 Counter-arguments and/or possible positive effects

Various perspectives that argue against negative genetic interactions include the following:

- Hatchery and wild fish are essentially the same and little domestication results from raising fish in hatcheries: The assumption is that since hatchery stocks came from wild stocks, sharing the same DNA, little genetic harm can be caused by releasing them into wild populations – "We breed endangered animals in zoos and return them to the wild. Why not salmon?" (Jack DeWitt 2001).

- Enhancement in hatcheries can "improve on nature": "… fish culture is a tool that can be responsibly used to develop genetic strains of fish to combat health issues such as whirling disease and possibly lead to better survival in the wild" (Incerpi, 1996 p.28). Selective breeding at hatcheries could focus on developing superior strains of salmon: "there is no reason that hatchery managers cannot focus on a more advanced measure of 'fitness' [than survival in the hatcheries]: survival over the entire life cycle, not just to the point of release. … In the long run, genetic engineering techniques may offer the ability to give salmon greater resistance against parasites, warm water, and other factors limiting salmon production." (Buchal 1998 p.145). In other words, hatchery operators could accelerate the process of natural selection.

- Enhancement in hatcheries can counteract other negative genetic effects on wild salmon, for example, those caused by the focus of fishing pressure on older (larger) fish due to size limits.

- Other impacts affect wild salmon before they suffer the consequences of genetic interaction: Populations will often go extinct due to demographic problems before loss of genetic variability can become a problem (Lande 1998 in Fleming and Petersson 2001).
- Frequent mixing of local wild and hatchery fish can reduce the degree of genetic differences that accumulate through domestication.

7.2.3 Experience and examples

Two processes that have occurred in the past are no longer debated as sources of genetic change and potential interactive effects. The use of non-local stocks for brood sources (i.e., use of a common hatchery stock throughout an area or transfer to another region) and maintenance of a closed brood stock or one that has been developed from a composite of a few local populations are both known sources of genetic change. These situations are not typical in the Salmonid Enhancement Program but have definitely occurred in past programs. Included in this type of situation are the recent studies of aquaculture strains of Atlantic salmon interbreeding with natural populations, and the very poor reproductive capability of the aquaculture fish in the wild (Atlantic salmon, McGinnity et al. 2003, Fleming et al. 2000; Brown trout, Hansen 2002). No documented examples of genetic impacts in B.C. or Yukon are available at this time. Information has not been collected here and more research needs to be done.

Reduction of the effective population size in hatchery stocks

Waples (2002a,b) has recently examined the relationship between the genetically effective population size of salmon and steelhead hatchery-based populations compared to the census or observed population size during a spawning year. Based on three studies of variation in family sizes in hatchery coho, pink, and chinook salmon (12 independent estimates), Waples (2002a) estimated non-random survival during the marine phase led to estimated reductions in effective size of 0-62% (mean 19%). In a separate analysis of genetic sampling data for Snake River spring/summer chinook, Waples (2002b) estimated that ratios of Nb/Nc (Nb is the effective breeding number within one spawning year, Nc is the census or observed number) varied from less than 10% to over 100%, but that the majority of values were in the 10% to 40% range. While techniques for measuring these effective population sizes are improving with the development of more sensitive DNA analyses, to date these data demonstrate that the effective population sizes in cultured populations may be substantially less than the observed number of spawners, frequently less than half.

Reduced reproductive fitness of hatchery fish in the wild

If reductions in the genetically effective population size are important to the survival of hatchery fish in the wild, then studies of the relative performance of hatchery fish in the wild compared to the wild fish should indicate poorer performance of the hatchery fish. Many past studies have documented this type of result but the cause of the reduced performance is very difficult to prove. Is the reduction due to genetic, environmental, or genetic and environmental interactions? These interactions could be social (i.e., during mating competition) and involve the recognition that hatchery fish are "foreign" to the natural population, or they could actually involve reduced genetic fitness of the hatchery stock. Fleming and Petersson (2001) reviewed the success of hatchery programs in sustaining natural populations, including a review of determinants of breeding success, and concluded that "where adequate assessments have been made, released fish frequently fail to attain self-sustainability and/or contribute significantly to populations." A recent study by Chilcote (2003) demonstrated a significant negative relationship between the proportion of hatchery steelhead spawning in natural populations and the productivity of the mixed population. Based on the study of 12 populations of steelhead salmon in Oregon, the study estimated that a 50% hatchery composition in the mixed spawning population would be expected to reduce the productivity by about 60%.

Clearly these types of results are continuing to cause concern regarding the net value of using hatchery fish to support natural production. The genetic basis of these concerns will likely become more apparent as new DNA methods are applied (Jones and Ardren 2003). For example, McLean et al. (2003) used DNA techniques to estimate differences between hatchery and wild steelhead (based on adult-to-adult production rates) productivity. Wild steelhead produced 9 to 42 times the adult offspring of hatchery fish transferred into a west coast Washington State stream (based on only two years of study).

An emerging issue in studies of reproductive performance is the need to consider the origin of the hatchery brood stock. In both Chilcote and McLean et al. the hatchery stock origins were not local. Since the use of locally derived brood stock is now the recommended process, others have argued that these results are not representative (for example, see Berejikian and Ford (draft report, 2004). More study will be necessary to determine how representative these published results actually are.

U.S. Pacific Northwest, Columbia River Basin

Hatchery practices in the U.S. Pacific Northwest were slow to change operations that did little to prevent genetic impacts on wild salmon. For decades, no attempts were made to keep track of the genetic history of hatchery releases; eggs were moved between hatcheries without regard for preserving existing runs; eggs were imported from stocks in other basins; and sperm from one captured male was used to fertilize eggs from dozens of females.

One of the largest hatchery programs in North America is coho salmon production in the lower Columbia River. Since the 1960s, transfer of hatchery populations between streams and inadvertent selection for run timing in the hatcheries has caused Lower Columbia coho to be comprised of a mixture of fish of various origins with no distinct wild population segment. At the same time, adult returns did not increase proportionately with hatchery supplementation and catch was not increased (graphic presentation in Riddell 1993a p.342).

Lichatowich (2001) provides an example in which coho salmon from one watershed were planted (i.e., released) into another but the planted stock was not resistant to a parasite that was present in the receiving stream. Surviving adults from the transplanted stock interbred with the native stock. A scientific study demonstrated that the interbreeding of the coho salmon reduced the offspring's resistance to the parasite (Hemmingsen et al. 1986). Such an effect on the progeny would reduce the productivity of the receiving population, but over time (in this particular example) the impact may be reversed through natural selection.

Recently, the Independent Scientific Advisory Board reviewed the efficacy of hatchery supplementation programs within the Columbia River basin (ISAB 2003-3). Supplementation is the use of hatchery programs specifically to increase the numbers of naturally spawning salmon. Concerning the risk of genetic impacts to natural populations, this scientific panel concluded:

> *"Contemporary genetic/evolutionary theory, and the literature that supports it, indicate clearly that supplementation presents substantial risks to natural populations of salmon and steelhead."*

7.3 Competition

7.3.1 Interrelationship of competition and predation

Competition and predation are interrelated. For example, competitive effects can be expressed as exposure to predators. More competition for food means that fish are more active and exposed to predators, resulting in higher mortality. Both competition and predation interactions can be affected by interrelated factors in the enhancement technique, e.g.:

- release life stage (e.g. fed or unfed: to river, estuary, or marine pens);
- body size at time of release (relative to wild at same life stage);
- release timing (before, with or after wild);
- number of juveniles released (relative to wild numbers).

Competition and predation are complexes of behaviours that are difficult to measure (White et al. 1996 p.23).

7.3.2 Possible negative effects of competition

Enhanced salmon can compete with wild salmon for:

- spawning area,
- freshwater rearing area and food,
- estuarine food, and
- marine food.

The primary factor is the addition of large numbers of hatchery fish to aquatic ecosystems that naturally have limited carrying capacity. If there is strong density dependence in survival rates for some life stages after hatchery release (that is, if high densities of fish cause survival rates to be higher), total recruitment may be limited by competitive interactions. Displacement of wild salmon by hatchery-produced fish can occur as juvenile fish from wild populations are subjected to competition from hatchery fish in freshwater and early ocean rearing areas.

Factors that worsen the effects of competition include:

- Hatchery fish have a tendency to consume more food than wild fish consume (Ray Hilborn, population ecologist at U of W, Seattle, in Raloff 2001).
- Releasing hatchery fish before wild salmon enter the system can give them an advantage.
- The larger the enhanced fish are relative to the wild fish with which they compete, the more likely they are to dominate the wild fish in competitive encounters over food or space. Hatchery fish do tend to be larger when rearing programs produce large smolts in an attempt to overcome the relatively poorer smolt-to-adult survival of hatchery-released fish compared with wild fish (Bilton et al. 1982 and Martin and Wertheimer 1989 in Flagg and Nash 1999).
- Competition can increase when large fish from hatcheries residualize – stay in the stream rather than out-migrate – for a prolonged period of time (Flagg and Nash 1999).

In the freshwater environment

Survival of wild salmon is much improved when fewer larvae or juveniles enter the pre-recruit life stages, apparently reducing competition in "foraging arenas" (Walters and Martell, in press, p.3-4 of ms.). The foraging arena is the area in which a juvenile fish feeds. When there are more fish competing for space in these arenas, the food available in them is reduced and the fish have to spend more time and/or cover larger areas to feed adequately, all the while at risk of predation. The result, in theory, is that juvenile survival rates of fish rearing in the wild declines if enhancement directly or indirectly increases the numbers of foraging fry or smolt.

An influx of hatchery fish may push a stream over its carrying capacity – the maximum number of fish that the stream can support. If freshwater habitats are fully subscribed by wild juveniles, larger hatchery juveniles may displace wild juveniles, preventing wild juveniles from establishing and occupying territories, or forcing wild fish into marginal habitats with low survival potential (Lichatowich 2001). In some B.C. hatcheries, production targets have been exceeded, releasing pre-smolts into habitat that is already at its carrying capacity.

Competition for freshwater habitat may again occur at the spawning phase of the life cycle. Genetic selection at hatcheries can favour early spawning adults. The fry from these fish tend to displace the fry of later spawning wild fish by using the full capacity of the freshwater habitat, and the adults may compete for mates (Lichatowich 2001).

Concerns about competition in streams are relevant to the stream-rearing species – chinook, coho, steelhead and cutthroat – but less relevant to pink and chum salmon that migrate to salt water soon after emergence. If hatcheries rear the fish to the smolt stage (especially the stream-rearing species) these fish are less likely to compete since they migrate to the estuary upon release. If the hatcheries release fish earlier, they occupy freshwater habitat longer and thus are more likely to compete with wild salmon. The main strategy in B.C. for production facilities is smolt releases. The number of fry and fed fry released has decreased in recent years.

In the nearshore environment

The estuary (coastal area under direct freshwater influence) and nearshore coastal zones are other habitats where carrying capacities may be exceeded. For example, substantial mortality of coho and fall chinook occurs during the first several months after leaving fresh water. For these species, major processes that limit production probably act before the earliest stage of measured recruitment (as indicated by strong correlation between total returns and returns at earliest stage of recruitment measured).

In the ocean environment

There is a finite supply of food available for smolts once they reach the ocean, so the addition of hatchery fish to the wild fish can increase competition for this limited supply. For example, coho salmon need a certain amount of growth during their first marine summer so that they can survive the fall and winter conditions in the ocean. Therefore, if hatchery-reared juveniles are added to the marine environment, this may increase competition for food that could then reduce the growth and increase the mortality of the wild fish (Beamish et al. 2002 p.63). Peterman (1984) has observed that large abundances of sockeye in the ocean can result in decreased average size of adults.

In some years the food supply in the ocean is better than others due to various broad-scale environmental forces (Beamish and Bouillon 1993 in Flagg and Nash 1999). For example, periods of warmth in the Pacific Ocean – "El Nino events" – coincide with poor food supply in near-shore areas (Raloff 2001). During these years of lower availability, competition for food from hatchery fish can put wild fish at risk. At this point in time, there are no ways of accurately predicting the change to a period of warming or cooling ("regime shifts"), so the addition of hatchery stock to the ocean during years of limited food supply cannot now be purposefully avoided.

7.3.3 Counter-arguments and/or possible positive effects

Countervailing views on the effects of competition include the following.

- There are no limits on the capacity of habitat: In the early years of enhancement, a popular assumption was that there must be adequate unused habitat and food supply to support the addition of hatchery fish to ecosystems without limiting their ability to support wild fish. The reality of limited carrying capacity is largely accepted today.

- Competition might be healthy for wild salmon: Increased "fair" competition (by equally sized wild and enhanced fish) may increase fitness of both wild and enhanced fish.
- More fish coming back to the spawning grounds add nutrients, expanding freshwater carrying capacity: Increased enhanced production can increase the nutrients and productive capacity of a watershed by adding the carcasses of dead spawners to the ecosystem. This increases the productive capacity for wild fish.
- Hatchery fish are too weak to compete with wild fish: "... even though hatchery-reared fish appear to be more aggressive than wild fish, and thus should be able to displace them in territorial contests, they suffer higher mortality in the wild." It is possible that the hatchery fish are unable to cope with the high cost of the aggressive behavior in terms of risk of starvation or predation (Einum and Fleming 2001 p.37).

7.3.4 Experience and examples

Snake River, Columbia River Basin

Levin et al. (2001) tested the hypothesis that massive numbers of hatchery-raised chinook salmon reduce the marine survival of wild Snake River spring chinook, a threatened species in the U.S. The researchers developed a 25-year time-series that demonstrated a strong negative relationship between the survival of the salmon and the number of hatchery fish released, particularly during years of poor ocean conditions. This study may have been the first to document a strong association of hatchery fish with the marine survival of wild populations. The authors conclude, "hatchery programmes that produce increasingly higher numbers of fish may hinder the recovery of depleted wild populations." (Levin et al. 2001 p.1153)

Prince William Sound, Alaska

Wertheimer et al. (2001) ascribe declining populations of pink salmon in Prince William Sound to oceanic conditions and see no evidence of any density dependence due to enhanced fry releases. However, when Hilborn and Eggers (2001 p.723) analyzed data related to the same processes they concluded that the data provide "strong evidence for the replacement hypothesis."

Coho and chinook in the Strait of Georgia

Walters (1993) concludes that declining abundance of wild coho in the Strait of Georgia is most likely caused by density-dependent competition between wild and hatchery coho salmon at sea (ocean carrying capacity limitations). He acknowledges, however, that oceanographic change and estuarine carrying capacity limitations cannot be ruled out.

Concerns about hatchery releases of chinook salmon have been expressed in connection with density dependent rearing limitations. Data on the numbers of chinook salmon smolts released from Fraser River and Strait of Georgia hatcheries and total production by year indicates reduced adult production for smolt releases greater than 8.3 million. Thus, "survival does appear to decrease as the numbers of releases increase. Other hypotheses have been proposed to explain this trend but the density dependence hypothesis can certainly not be rejected based on these data." (included data from 1971-1987 brood years, Riddell 1993a p.344). Perry (1995 p.157) agrees that "The survival data for Strait of Georgia hatchery chinook salmon suggest possible density-dependent mortality" and also compares these results with similar results for coho salmon in coastal Oregon.

Coho in the Eagle and Coldwater rivers

A study of coho enhancement in the South Thompson River explored the potential competition of hatchery and wild fry in freshwater habitats (Pitre and Cross 1993). In the Eagle River, coho escapement showed an initial positive response to hatchery releases but then declined. The wild return per spawner and the hatchery fry survival data both "indicated a decline with increasing fry abundance, suggesting that rearing capacity was reached." (Perry 1995 p.154) On the Coldwater

River results differed, indicating that the hatchery releases have made a significant contribution to the rebuilding of the coho salmon stock (p.155). The difference could be due to the fact that Coldwater Hatchery fry are released into the upper river, which escaping adults can access only in high-water years, leading to little interaction with wild salmon; however, Eagle hatchery fry are distributed throughout the available coho salmon rearing habitat. It should be noted that based on these results, fry releases were discontinued in the Eagle River and Perry notes that "populations should be monitored and hatchery release numbers should be adjusted in accordance with wild fry abundance."

7.4 Predation

7.4.1 Possible negative effects

Negative interactions related to predation may occur when:

- enhancement fish prey on wild salmon, potentially including intra and inter-specific predation;
- enhanced populations attract predators;
- influences of fish from enhancement decrease the predator avoidance behaviour of wild salmon.

Enhanced fish may prey on wild fish enough to affect production of wild salmon. When fish-eating fish are stocked, they are likely to prey on other fishes, including wild salmon (Miller and Pister 1971, Sholes and Hallock 1979, Garman and Nielsen 1982 in White et al. 1996 p.22). For example, coho smolts are known to prey on pink salmon fry. Another possibility is that where different year-classes of juveniles share the same nursery area, older juveniles may cannibalize younger ones (Walters and Martell, in press, p.6 of ms).

Stocked fish concentrations attract higher numbers of predators, which then also prey on wild fish (Beamish et al. 1992 in White et al. 1996). There are a number of reported cases of predators responding to the abundance of hatchery releases. These include birds such as gulls, fish such as trout and dogfish, and seals. Large, continuing releases attract and support increased predator populations which concentrate downstream of hatcheries and prey on migrating juveniles, both wild and enhanced.

There may also be genetic considerations, given that juvenile salmonids from wild and hatchery populations differ in predator avoidance behavior and ability (Riddell and Swain 1991, Johnsson and Abrahams 1991 and Berejikian 1995 in Flagg and Nash 1999). Hatchery salmon may be worse at predator avoidance than wild fish because of having less experience with predators. With a genetic basis to these behavioural traits, it is possible that this behavior may be transmitted to the natural population after inter-mating. It is also possible that if the hatchery fish are larger than wild fish, it could result in predators taking a higher percent of wild than hatchery fish.

7.4.2 Counter-arguments and/or possible positive effects

Predator response to fish abundance can work in favour of wild populations mixed in with enhanced. Large quantities of less behaviorally fit or undersized enhanced salmon from hatcheries might provide extra prey which could satiate predators and thereby increase survival of wild salmon by decreasing predation on wild populations.

7.4.3 Experience and examples

Harbour Seal Predation in Courtenay River

Seal and sea lion predation on adult salmon is well documented. However, predation on juvenile salmon and whether these predators respond to enhancement facilities is not as well documented, with the exception of harbour seals (*Phoca vitulina*) in the Courtenay River (lower Puntledge River system, Brown et al. 2003). Brown et al. provide an excellent summary of the interaction of seals with adult salmon and attempts to control the predation rate, including the eventual lethal removal of some seals. The report does not comment in depth on predation on juvenile salmonids released from the Puntledge River hatchery. The most thorough report on juveniles is Olesiuk et al. (1996). Methods for disrupting this predation are discussed in Yurk and Trites (2000).

Seals are known to be opportunistic predators; they respond to availability of prey and feeding situations (e.g., constrictions in flow, or seasonally available food sources). Seals in the Courtenay River developed a unique seasonal feeding behaviour below two bridges in the lower river in response to the availability of large numbers of prey. Olesiuk et al. estimated that, during the spring of 1995, seals consumed approximately 16% of the chum fry emigration and 15% of the coho. These investigators also reported that a limited number of seals in the herd learned this feeding behaviour and were repeatedly observed at these bridges. When the few seals that had learned this behaviour were removed from the area, the predation problem decreased to normal levels.

In the summer and fall the numbers of seals in the Courtenay estuary triples in response to the return of adult salmon. The sequence of salmon return is summer chinook, pink salmon, and fall chinook, followed by coho, chum, and steelhead from mid-fall into the winter. Various estimates of predation rates, based on the results of surveys done in the 1990s, indicate that between 23-35% of summer chinook, 3-4% of pink salmon, and 36-46% of fall chinook have been killed by harbour seals (pg. 19, Brown et al. 2003). These predation rates were compared with fishing mortality rates on summer chinook (pg. 110, Rice et al. 1997). Trites and Riddell estimated that, in 1980, total fishing mortality accounted for 74% of the summer chinook returns and harbour seals for an additional 9%. However, by 1990, conservation actions in fisheries had reduced exploitation rates to 32%, but predation rates had increased to 24%.

Harbour seals in Courtenay estuary have likely been natural predators in response to large numbers of pink and chum salmon, aided in their predation efforts by the narrow lower river situation. However, the development of the hatchery in the mid-1970s is also considered a likely contributor to the seals' response to the juvenile salmon.

A 1924 controlled experiment on two creeks

In 1924, Harley White, a fish scientist from Queen's University, hypothesized that predation was a major agent of decline in juvenile fish populations enhanced by hatcheries. He conducted a controlled experiment by removing most of the wild fish from one creek, leaving the fish in the control stream, and adding 5,000 trout fry to each creek. In the creek that had had the fish removed, predation was 70%, and in the creek where the original fish had been left, predation was 96%. White was shunned by fish culturists for these results which suggested that loading freshwater habitat with hatchery fish increases predation (Taylor 1999 p.118). By today's scientific standards, the research can be questioned for being based on one example rather than several (lack of "replicates"), and in respect to other aspects of his experimental design.

Predation on coho salmon in Oregon coastal basins

A recent study of predation on coho salmon in Oregon coastal basins concludes: "Evidence suggests that productivity of wild populations can be reduced by the presence of large numbers of hatchery smolts in lower rivers and estuaries that attract predators." (Nickelson 2003 p.1050)

Study showing lack of hatchery salmon predation on wild salmon

White et al. (1996 p.23) state that "In a substantial British Columbia river (20-300 m3/s discharge during smolt migrating), no hatchery chinook salmon smolts were found to have eaten salmonids; it appeared that wild fry occupied shallow river margins, whereas smolts occupied deeper water (Levings and Lauzier 1989)."

Merganser predation showing possibility of protective cover for wild stocks

In non-tidal areas, Wood (1985) found that mergansers congregated on streams where juvenile salmonid abundance was enhanced by hatcheries or spawning channels. Merganser visit duration increased exponentially with increasing fish density and decreased with searching time required until the first capture (Wood, 1984). Mergansers flying by were attracted to others feeding in an area. Also, there were more breeding pairs of mergansers in such high salmon abundance areas (Wood, 1986). As some mergansers choose nesting sites from previous experience, the resident merganser population abundance would tend to increase in response to juvenile salmon abundance resulting from enhancement. This situation is most pronounced when enhanced fry or fed fry are released into streams to rear there. (Releasing fed fry was a common practice in the past, but is much reduced now.)

Mergansers rank among the largest, in terms of appetite, and most efficient predators of juvenile salmon; what is more, they are relatively common and congregate wherever salmon density is high. Despite this, the overall mortality rate due to mergansers was depensatory – mergansers were simply swamped by the output from spawning channels and hatcheries. For example, Wood (1985) estimated that the daily consumption of coho smolts per merganser would not exceed 500g per day (about 11 or 12 smolts).

Wood (1987) concluded that "Probably no single species of avian predator is capable of inflicting compensatory mortality on juvenile salmonids during their seaward migration. If this is true, it follows that predation by all fish-eating birds, acting in concert, must also be depensatory and that salmon populations cannot be regulated by avian predation during their seaward migration."

Such depensatory mortality means that enhanced production could provide protective cover for wild stocks, thereby increasing wild survival.

Most other sea birds are opportunistic fish-eaters. However, Mace (1983) documented an aggregation response by Bonaparte's gulls to the chinook smolt migrations through the Big Qualicum estuary over several consecutive years. But Big Qualicum appears to be an exceptional case, perhaps because of the unusually high densities of chinook smolt released there. Mace found no evidence of predator aggregation in response to chinook smolt releases from the Capilano River hatchery during the same period.

7.5 Fish health

7.5.1 Possible negative effects

Enhancement projects can raise the potential for disease transfers to and among wild fish through a number of mechanisms.

Stress or diet can make fish in hatcheries more susceptible to disease (lowering immune response). Crowded conditions may increase the transfer of disease from fish to fish. Both of these factors can make the hatchery fish a potential reservoir of pathogens (sources of viruses, bacteria and parasites). Some diseases may not show symptoms in fish while in the hatchery and thus go undetected and therefore untreated. If infected hatchery fish are released they may pass their pathogens on to wild fish. If diseases exist in the hatchery, enhancement facility effluent water can carry pathogens into local streams or rivers.

An example of a disease that must be dealt with in hatcheries is bacterial kidney disease (BKD), which induces severe, chronic inflammation in the kidney, other organs, and to a lesser extent, the muscle. The disease develops slowly from the time of infection into a chronic condition and can become terminal (Whoriskey 2000). The BKD bacterium is transmitted vertically through the egg, as well as horizontally (in freshwater and seawater). The disease can occur in freshwater, and fish can carry the infection to seawater (Evelyn et al. 1998). Outbreaks can occur throughout the year and at all stages of the life cycle. The presence of bacteria in the kidneys has been found to be directly proportional to rearing density (Mazur et al. 1993 in Flagg and Nash 1999). This results from the lowered resistance to infection as a result of crowding, and possibly due to the ingestion of fecal matter carrying high loads of bacteria from infected fish during feeding.

Species that are reared longest in the hatchery (coho, spring chinook, steelhead and cutthroat) are at the highest risk for disease. Some species are more susceptible than others to certain diseases. For example, sockeye, pink and chum are extremely susceptible to bacterial kidney disease, and sockeye are susceptible to infectious hematopoietic necrosis (IHN). IHN is one of the most costly viral diseases of cultured salmon in North America and has been recently identified as the cause of significant mortalities in farmed and enhanced salmon in the Pacific Northwest. The disease process is very aggressive and acute, particularly in smaller juvenile salmon (Saksida 2002).

If hatchery stocks are not endemic (i.e. are transferred from other regions) this can risk the spread of exotic pathogens to an area that is outside of their historic range. The wild fish in the area will not have evolved the resistance to these diseases and may easily succumb to them. Conversely, the broodstock that are moved to a hatchery from another watershed may lack the genetic resistance to a disease that the fish native to the area have developed. If the less resistant stock from the hatchery interbreed with the local fish, the offspring may be less resistant than the original wild stock (Lichatowich 2001).

In large enhancement projects involving channels, over-crowding has the potential to increase the transfer of disease, as in hatcheries.

7.5.2 Counter-arguments and/or possible positive effects

Two counter-arguments to the negative impacts of fish health interaction follow.

- Wild salmon have natural immunity to the diseases in hatcheries: The diseases in hatcheries are endemic to natural populations which have evolved to have some genetic resistance (immunity, or adaptive responses) to the diseases. For example, the causative agent of BKD, *Renibacterium salmoninarum*, is ubiquitous in wild Pacific salmon.
- Some forms of enhancement can improve the health of wild fish: As obstacles are removed through habitat enhancement efforts, improved access could reduce the injuries from difficult upstream migrations, thus reducing the susceptibility of the fish to some diseases.

7.5.3 Experience and examples

Spread of disease through the transport of fish

In various parts of the world, the movement of fish from one region to another has been associated with changes in the occurrence of disease in native fish stocks (Stephen and Iwama 1997). For example, in the United States Pacific Northwest, whirling disease is an exotic parasite thought to have arrived in transfers of cultured (hatchery and commercial) trout (Nehring and Walker 1996).

Babine Channels and Skeena River Sockeye

- The Babine enhancement channels have had disease outbreaks associated with large escapements and warm water conditions (Wood pers. comm. 2003).

7.6 Habitat degradation

7.6.1 Possible negative effects

Enhancement project design and operational issues can lead enhancement to have local or watershed impacts on the habitat of wild salmon and their ecosystem. Several of the potential issues listed below are from White et al. (1996 p.22 Table 3):

- Nutrient loads in waters receiving hatchery effluent (after water treatment and waste management) can promote biotic change in the freshwater habitat of wild salmon.
- Diverting water from streams or from their groundwater aquifers for use in channels or hatcheries reduces flow in the water supply stream.
- The temperature of waters receiving hatchery outflow may be changed.
- Regulation of river flow to benefit migration of hatchery fish can result in disadvantageous flow conditions for wild fish (not a common practice in B.C.) (Hilborn and Hare 1992 in White et al. 1996).
- Physical interference with migration and spawning by hatchery weirs and traps can block or delay adult migration of wild fish, and disrupt seaward migration of wild smolts. (White et al. (1996) report that in some cases wild spawners are deliberately blocked from proceeding upstream of water supply intakes for fear they will spew disease organisms into the hatchery (p.21))
- Where hatcheries block migration or adults are taken from a wild population for hatchery use, upstream areas are deprived of the nutrients from decaying carcasses (Trotter 1994 in White et al. 1996).
- Hatchery structures and activities can destroy riparian features (structural habitat in stream channels and riparian zones). Structures and activities may include water diversion structures, fish weirs and traps; and other facilities such as roads, parking lots, picnic areas and associated human activity. These alter stream channel and banks by hiding cover, pools and spawning riffles.

7.6.2 Counter arguments and/or possible positive effects

Some argue that the addition of enhanced salmon to the ecosystem can improve habitat for wild salmon.

- Salmon help to maintain spawning gravel when they dig their redds to spawn.
- Salmon carcasses provided from enhanced stocks feed insects and juvenile salmon and the nutrients stimulate plankton growth that increase the number of salmon that an area is able to support.

7.6.3 Experience and examples

Although the literature has not provided specific experience of negative habitat impacts from enhancement facilities, the authors have personal knowledge of three examples of such impacts:

- Water diversion happened in early hatchery construction in B.C. but is now frowned upon.
- The first Fulton channel caused controversy as it impacted natural habitat in the river.
- The Babine spawning channels bring millions of pounds of salmon carcasses into the watershed each year.

8. PROTECTING WILD SALMON: ASSESSMENT, MITIGATION AND REFORM

Impacts of enhancement on wild salmon can only be known if monitoring, assessment and evaluation are carried out. Once impacts, or at least risks of impacts, are identified, then mitigative measures can be taken to manage the risk. When the potential for taking additional measures is explored, and programs for communicating and implementing mitigation are developed, this is often called "hatchery reform." These three themes are discussed in this section. Recent developments relevant to the future of enhancement are also reviewed here.

8.1 Assessing enhancement

Assessment in the salmon management context consists of fishery statistics such as number of recruits per spawner, smolt-to-adult survival, spawning escapement, and fishing mortality. Monitoring is the activity of gathering the data required for these reports on a regular basis. Analyzing the results of monitoring to make decisions about the effectiveness of enhancement is called evaluation. In practice, however, the three terms – monitoring, assessment and evaluation – are often confused and used interchangeably.

As explained below, assessment of enhancement is important to the ongoing improvement of the effectiveness of enhancement activities, including reductions in any negative impacts they might have. Section 9 probes further into the kind of research and information that is needed to increase our knowledge of enhancement effects, and particularly to better understand interactions with wild salmon.

8.1.1 Information needed for effective assessment of enhancement

Ideally, the risks and benefits of enhancement should be comprehensively evaluated before projects are launched (Hard 2002 p.83). Once underway, monitoring and evaluation of enhancement programs should occur on an annual basis in order to support an adaptive management approach (Peterson 2002 p.13). Evaluation should be integral to all projects. Criteria and effort invested in assessment may vary by the scale and type of enhancement activity and according to the risk of impacting local natural populations (Riddell 1993a p.350). Assessment should consider not only the number of juveniles released but also the number of adults produced through enhancement. Assessment should also take into account that enhancement is only one of many pressures on wild salmon (see Section 1.3 and Appendix 4).

Results of improved assessment can support adaptations in enhancement activity or technology to various ends. Annual evaluation and abundance predictions can help to maximize yields when available and to minimize mixed-stock fishery impacts when production declines (Riddell 1993a p.350). If assessment programs are to provide data that will tell managers whether enhancement is achieving its objectives, the goals of the program must be clearly stated, in turn guiding the identification of performance measures. For example, the Coho Steering Committee set a goal of increasing productivity in stocks having difficulty rebuilding despite reduced exploitation rates. Assessment was called for to identify stocks that are not rebuilding and to evaluate the success of enhancement in rebuilding stocks within this criterion (Coho Steering Committee 1992 p.34).

8.1.2 Overview of assessment methods and programs

Marking techniques

A foundation of assessment is the ability to identify or "mark" individual fish and to observe the fish more than once. This way, data can be gathered about processes between when the fish was marked and when the fish was recovered (whether in a fishery, hatchery or spawning ground).

Techniques to mark fish (enhanced and wild) can distinguish them as individuals or as members of a production grouping.

Marking techniques include:

- fin clips (e.g., removal of a fin for an external mark, limited applications except for the removal of the adipose fin that has identified juveniles with coded-wire tags);
- tiny coded wire tags (CWT) that go into the cartilage in the nose of the fish;
- otolith marking, either thermally or with strontium (internal only);
- other forms of marking such as biomarkers (parasites, DNA, scale pattern analysis, etc)
- more advanced electronic tags such as PIT (Passive Induction Transmitting) tags;
- radio tags for tracking individual fish; and
- external tags such as the flat "Peterson disk tag" with writing on it.

Either juveniles or adults are marked. Juveniles may be marked in the hatchery through techniques such as coded wire tags or thermal marks. Recovery of these fish provides information about the specific stock from a hatchery. Marking adults by using various tags is done in a fishery when fish are caught, marked and released. When these fish are recovered, it provides information about where they have traveled but not where they originated from – unless they are recovered in spawning areas.

Gathering of data at enhancement sites

Opportunities for monitoring and data collection are often provided at enhancement sites. This information can be used both to assess the effectiveness of the facilities and for broader fishery management purposes. For example:

- Some *fishways* are used as a convenient means to count the number of fish passing upstream to provide stock assessment information. Fishways in which such counts have been made include Hells Gate, Meziadin River, Stamp Falls, and Moricetown Falls. Some fishways also offer opportunities to count tagged and untagged fish.
- Some *restoration projects* provide information that can be used for fisheries and habitat management. However, this is mainly local and specific to the project area. Large projects may provide marking information.
- The monitoring before and during *lake and stream enrichment* has provided an excellent baseline of information on an array of stocks about which little had been previously known. In monitoring freshwater survival it has also provided information on marine survival that would otherwise have not been known.
- SEP marks chums at *spawning channels* with fin clips to help estimate the number of returning adult salmon, and the catch in different fisheries. This information helps in planning for harvesting.
- Because *hatcheries* control the environment of the fish and rear fish they have the ability to induce marks on the otoliths or scales, do fin clipping, apply tags before the fish are released. The most important marking program along the Pacific coast has been the coded-wire tag program. SEP has an excellent record of applying coded-wire tags for assessment. This can generate much information about migration rate, route and timing, growth and survival. This

information is projected to wild stocks in the area and is an important basis for assessment and management. Enhancements also often provide a continuous record of environmental parameters (water temperature, quality, etc.).

Use of information from assessment

The information that would ideally be gathered by assessment in order to further understanding of enhancement effects on wild salmon would include:

- Number of fish released from facilities by species, stock, size, etc. and numbers of marks would be monitored for the various production groups.
- Reliable information on catch of fish by fishery, including terminal or ESSR fisheries (Excess Salmon to Spawning Requirements – see Glossary). Estimates of the incidental mortality on these fish by fishery would be useful.
- Catch data needs to be known by time and location so that migration patterns can be studied.
- Sampling programs in all fishing areas are required to sample for and recovery marked fish.
- Spawning escapement to the facility and to adjacent streams, the escapement of both wild and enhanced are required in order to estimate total production in fishing areas.
- The proportion of hatchery fish on natural spawning grounds is required, plus data on size and age of the returning hatchery and wild fish.
- Documentation is required for all methods used in sampling and estimation procedures.

Further, to assess the impact of hatchery fish mixed with a natural population, some basis for comparison with a natural population that is not mixed with a hatchery population is required. Such a population would experimentally be called a control population. However, since natural environments can never be strictly repeated, these natural production systems could be thought of as reference streams. Ideally, all of the information required above would be required on each reference stream but, in most cases, these natural populations are not marked. The critical information to acquire for the reference streams are: numbers of spawning fish by age, accounting for any terminal catches or mortalities on these populations and the numbers of smolts produced from each spawning year.

Hatchery, and in some cases wild, fish are marked to provide many types of information. The following are examples relevant to enhanced-wild salmon interactions:

- Evaluation of selective, "mark-only" fisheries is done by coded wire tagging two identical groups of fish, one with an adipose clip to represent hatchery fish and one without an adipose clip to represent wild stocks. This allows measuring the harvest rate of the adipose clip group, which can be retained by fisheries, and the relative mortality rates of both groups, to estimate the mortality from releasing the unclipped group.
- Representative stocks of wild juvenile migrants or the fish from hatchery supplementation are tagged and used as a "wild indicator" for stock assessment, particularly for assessing release to adult survival. An application of this is that some stocks are marked for use by the Pacific Salmon Treaty for monitoring fisheries constrained by Individual Stock Based Management (ISBM) plans. An ISBM fishery is an abundance-based regime that constrains the fishing mortality for a stock group within the fishery.
- Wild stocks are marked to provide time series data on survival and other stock assessment factors.

- Hatchery stocks may also be marked to assess hatchery strategies, identify harvest impacts on the stocks and for monitoring stock recovery.

An example of how marking techniques interact with monitoring objectives is hatchery mass marking programs. These are designed to allow selective fishing through a fishery that takes only the fish with clipped fins. However, this technique does not permit the origin of the fish in the catch to be determined. For example, a clipped coho caught in the Strait of Georgia fishery could originate from any hatchery on the east coast of Vancouver Island, the Fraser, the Georgia Strait Mainland or in the U.S. (Puget Sound, Juan de Fuca). To determine stock origin in these instances, the only tool currently available is the CWT program.

Although marking programs were initially developed for assessment of hatchery programs and benefits, the data has become fundamental to the management of chinook and coho salmon coastwide. These species are primarily exploited in fisheries that simultaneously harvest many populations (i.e., mixed-stock fisheries). However, before the coded-wire tag program, the total fishing impact on one population over all fisheries was largely unknown. Marking programs in facilities allowed for tracking the catch of a marked group of hatchery fish through the fisheries, sampling for the numbers of tags in the spawning escapement, and subsequently estimating the total fishing mortality and marine survival rates of these marked fish. The application to managing unmarked natural populations was possible since the fisheries operated equally on marked and unmarked fish (until very recently). Therefore, the exploitation rates estimated for marked hatchery fish could also be applied to the natural stocks. The survival rates of hatchery fish were not assumed to represent the natural but were used as an index of survival between years. Essentially all of the advancements in managing chinook and coho salmon over the past twenty years have been related to these coded-wire tag programs and the annual release of tagged groups from hatchery and some wild populations. These populations are frequently referred to as indicator stocks.

Species and stocks assessed

A number of enhanced and wild populations have standardized monitoring as indicator stocks. This program provides in-depth information that is generalized to other populations in the area. The indicator stock program provides valuable information for fisheries and habitat monitoring and research as well as enhancement.

Only coho, chinook and chum are currently marked with coded wire tags (CWTs) or finclips and their returns estimated. Previously, pinks were also marked. Steelhead and cutthroat are fin-clipped at a number of provincial facilities to allow for freshwater mark only fisheries. Outside of facilities there is some marking of wild coho populations. SEP has marked wild chum and coho stocks from a few restoration channels for assessment purposes. The program also marked wild chinook from the upper Big Qualicum for several years in the late 1980s and early 1990s as part of the Georgia Strait chinook rebuilding program. The Stock Assessment Division of DFO is currently marking wild Toboggan Creek coho smolts in a direct comparison with Toboggan Creek enhanced fish. There are wild coho stocks marked by DFO's Stock Assessment in Lachmach River in Northern B.C., Black Creek on Vancouver Island and in the Salmon River in the lower Fraser.

A number of sockeye releases from hatchery type operations (e.g., Pitt, Adams, Henderson) have been otolith marked either thermally or with strontium to provide an evaluation tool. Many other populations and species have also been otolith marked (e.g., WCVI chinook and chum, Quinsam and Chilliwack chinook. For the Skeena, the enhanced contribution is estimated using run reconstruction. Sockeye populations in the Fraser Basin are generally assessed but not for direct comparison with enhanced stocks, which are monitored .

Ongoing assessment of SEP enhancement activities

Assessment of enhancement facilities varies, mainly depending on the type of enhancement and the scale of project releases, with more intensive assessment for more intensive enhancement projects. For example, assessment of fishways and small habitat improvements may be limited to whether adult and/or juvenile fish use the facility. Post release assessment depends on facility objectives and feasibility of assessment. Different levels of assessment may address the following questions:

1. Do adult and/or juvenile fish use the facility? (primarily in connection with small projects)
2. Does spawning and/or rearing result in average or better survival? (primarily in connection with average sized projects) Trends and changes in survival with different strategies are assessed to learn about different production strategies.
3. How many juveniles leave the facility? Every facility with human controlled spawning, incubation or rearing must answer this question.
4. How many adults are returning, based on marked releases with adult recoveries in fisheries and spawning areas? (e.g., using indicator stocks)

Assessment of increased access, or improved or restored natural habitat

Methodologically, habitat-oriented enhancement activities are more difficult to assess than others: "Hatchery production is the easiest enhancement technology to assess and habitat improvement projects are the most difficult." (Coho Steering Committee 1992 p.34) Unmanned channels and fishways (minimal or no staffing) were not provided with ongoing operating budgets and so production associated with these sites is not monitored. However, a few fishways, such as at Stamp Falls, are monitored for stock assessment. Some habitat improvement projects are very difficult or not feasible to assess.

Lake enrichment assessment

Lake enrichment assessment has been based on the response of lake plankton and how the number and size of sockeye juveniles respond. The sockeye have been monitored primarily by acoustic means, so there may be a question whether all the targets that have been recorded were in fact sockeye. However, in most lakes acoustic counts have been backed up by trawl sampling, which provides information on species composition and abundance.

Most of the 18 enriched lakes have been monitored before and during enrichment. Monitoring was not conducted in all years of enrichment due to budget limitations. Enrichment was stopped in all but two lakes (Woss and Great Central) because of reduced budgets and reduced marine survival. Only two lakes (Chilko and Henderson) have been assessed after fertilization stopped to determine what impacts reduced nutrients have had on sockeye survival and growth. Findings to date indicate that enrichment increased the survival and average size of juvenile sockeye.

Hatchery assessment

Egg to fry and fry to smolt survivals are monitored within the hatchery. Different groups of fish are marked and released and then sampled for during fisheries, at hatcheries and in some cases adjacent natural areas (as describe above).

Assessments are usually related to individual enhancement facilities and are not generally done for a composite of all facilities. Enhanced and wild population interactions at this composite level are thought to be the cause of the recent decreased percent of wild coho in the Georgia Strait (Sweeting 2003). Issues not generally addressed relate to composite hatchery and enhanced outputs (e.g., total releases into Georgia Strait) and impacts on predation, competition, and mixed stock fisheries.

Hatcheries aim to achieve *targets* set by DFO.Targets could be expressed as juveniles released or eggs incubated, but are ultimately for adults returning or the numbers of juveniles to be released as designed for each facility.. Targets may be set by run timing; e.g. for Chilliwack coho there is a separate target for early, middle and late portions of the run. Targets are reviewed annually but generally do not change that much unless there is specific change of strategy that has been reviewed departmentally. For a few stocks the number of coho fed fry that are released are adjusted based on the wild escapement. The outcome of some assessments has led DFO to discontinue certain strategies.

Provincial assessment

A spokesperson for B.C.'s enhancement program recently commented on the need to improve monitoring and evaluation:

> *"One of the great failures of our stocking program (and of a lot of hatchery programs) is the lack of ongoing evaluation. We have gone through periods in our program in the last ten to fifteen years, up until 2000, where we were spending virtually nothing on evaluating either the success or the impacts of stocking programs. Also, almost nothing is being done with regard to monitoring the health and distribution of our wild stocks." (Peterson 2002 p.12-13)*

The Inland Sports Fish Development Initiative is assessing the province's monitoring program. The issues it is addressing are (Peterson 2002 p.14):

- Monitoring health/distribution of wild stocks/fisheries
- Relative growth and survival of various hatchery stocks
- Cost effectiveness of stocking programs
- Biodiversity-sensitive stocking policy
- Impact of various regulatory regimes (catch and release, etc.) on wild stocks.

The province's "Living Gene Bank Project" (described in Section 3.4.2) is being carefully assessed through a research program. All fish will be marked; the evaluation program will continue for ten or eleven years. The project will assess the returns from the program, if any, and monitor three control systems that are not being stocked (Peterson 2002 p.15).

8.1.3 Adequacy of and capacity for assessment

The Salmonid Enhancement Program is among the best monitored and assessed enhancement programs in the world. The information gathered during the peak years of SEP's extensive coded wire tagging, tag recovery, and monitoring of stocks in the areas of enhancement facilities provides a data base of long-term value for the assessment and management of both enhanced and wild stocks. However, monitoring is far from adequate to answer all of the questions about the impacts of enhancement on wild salmon. There are no programs to provide the information necessary to assess interactions between enhanced and wild salmon or to develop effective strategies to minimize adverse interactions. This level of sampling and assessment would require changes in enhancement strategies as well as increased resources.

Most importantly, program cutbacks in recent years have decreased monitoring and assessment. Funding for research into emerging enhancement-related issues is not adequate to answer the many new questions that have emerged. Of particular concern would be the reduction of coded wire tagging as a tool for following enhanced fish through their life and measuring survivals, straying, migration routes and timing, and harvest rates.

Between 1990 and 1998, over $1 million was cut from SEP's budget for project assessment and research. The number of facilities marking salmon species has decreased, as has the scale of mark sampling programs at all sites. For example, chums are only marked at a few facilities (e.g., Snootli and Big Qualicum). SEP discontinued enhancement on the Stave River in 1997 but has maintained an adult escapement program to monitor stock trends post enhancement. Additional wild coho marking programs have been implemented by the Stock Assessment Division in the past few years, but are in jeopardy because of funding pressures (e.g., Pitt River, Keogh River). There are currently no wild chinook marking programs, largely due to costs and difficulties in tagging wild juveniles. Because of the high costs of electronically sampling for CWT and the increased uncertainty of survival and exploitation rate estimates due to unknown release mortality on unclipped fish, both Canada and the U.S. are starting to look at alternate methods. Other techniques being explored for assessment include DNA analysis. These do not lend themselves to exploitation rate analysis or easily adapt to real time management.

Problems with lack of sufficient assessment of enhancement activities are not unique to B.C. In 2000, the Independent Scientific Advisory Board of the Northwest Power Planning Council (now the NPCC) provided detailed recommendations for hatchery monitoring and data collection and analysis systems and programs (ISAB 2000-4). The Board noted that the lack of such systems was handicapping the hatchery analysis in the Columbia Basin. The recommendations were adopted and were used in the major data collection effort that was part of NPPC's recently-issued Basin-wide Draft report (NPPC 2003). The Northwest Power and Conservation Council's Columbia River Basin Artificial Production Review and Evaluation recently noted that,

> *"most hatcheries do not [collect appropriate information]. Performance ... often cannot be determined for a given hatchery. ... routine monitoring and data collection is often sacrificed to budget priorities because of the perceived need to maintain production numbers. The result of this is that it is impossible to assess the performance of hatchery programs or to distinguish successful from unsuccessful programs." (NPCC 2003 p.63)*

While data collection systems in B.C. hatcheries have not been rigorously reviewed as in the NPCC case, it is likely that B.C. monitoring and data collection has been more rigorous and consistent. Nevertheless, all SEP facilities should be thoroughly reviewed, including their objectives and targets for each stock. Walters and Martell (in press) have presented a recommended list of key monitoring and experimental requirements, noting that, while they might increase the cost of most enhancement programs, they were justifiable investments because of their possible ability to lead to reduction of net deleterious effects of operations.

8.2 Mitigative measures to reduce negative interactions

The risks to wild salmon stemming from enhancement were reviewed in Section 7. In this section we describe practices that have been developed to mitigate risks and minimize potential impacts on wild salmon. Many relate to hatchery operations; some relate to other types of enhancement. In some cases, a recommended practice will affect more than one interaction category. In other cases, for example, mixed stock fisheries, some measures are taken within enhancement facilities, others beyond them.

Operational guidelines and best practices are being updated in SEP and are being used to guide operations in all facilities. It is anticipated that, when finalized, these guidelines will be formalized and publicly available.

Measures that have been developed to reduce mixed stock fishery impacts:

- To limit fishing effort responding to fish abundance, commercial area and gear licensing have been implemented to significantly reduce the movement of the fleet between areas. Also, the number of commercial fishing vessels has been reduced to less than half that in 1995.

- Reduced fishing pressure overall through closing certain rivers, limited entry and lower catch limits can ensure that harvest rates are sustainable by natural populations. Limiting fleet mobility by area licensing limits the amount of effort that can respond to fish abundance. Managing to a catch ceiling or to at-risk populations, instead of total abundance, can mitigate mixed stock fishery impacts.

- Sequential fishing has been significantly reduced by elimination of fisheries in areas such as Milbanke Sound, Laredo Channel, and Rennel Sound, and by time and area restriction in other fisheries, such as Johnstone Strait. This has particularly reduced sequential harvest of sockeye, pink and chum and to a lesser extent chinook and coho.

- Improved knowledge about stock specific migration rates, routes and timing allows more stock specific management and harvesting. For example knowledge from SEP and other coded wire tagging allowed selective protection of the at risk Thompson and Upper Skeena coho stocks.

- Fertilization of lakes for sockeye has been proposed as an alternative to harvest rate reductions for dealing with the effects of mixed stock fisheries. It is seen as a technique for improving the production of weaker lines (Bradford et al. 2000 p. 670).

- Implementing harvest strategies of a selective or terminal nature wherever these can provide harvest opportunities on stocks, such as hatchery fish, that can sustain higher exploitation while protecting weaker stocks. Such strategies incorporate clear definitions of achievable harvest objectives and descriptions of where and how harvest will occur. Selective harvesting has been implemented to reduce the harvest of wild salmon while sustaining the harvest of enhanced fish in areas of B.C. (e.g. Skeena sockeye, coho).

- Pilot selective harvesting projects in B.C. have demonstrated that gillnetting, seining and trolling can conduct species-selective harvesting. When operated in conjunction with time and area fishing, they can be somewhat population selective (DFO 2001a and 2001b). The least population-selective fisheries are likely the ocean hook and line fisheries on chinook and coho but species to be protected could be released. Another key to successful selective harvesting is information on migration rate, route and timing of populations for prescriptive fisheries.

- DFO has implemented selective fishing to protect at-risk coho stocks. Although regular fishing methods result in high mortality, in selective fisheries, fishers were required to use selective gear and methods, including live-release – or the fisheries would be closed.

- Mass mark selective fishing has the most potential to significantly reduce the level of impact of mixed stock fishery interactions on wild coho. Fishery regulations impose retention restrictions that only allow killing of marked hatchery coho. For example, the restriction that only allows sport retention of hatchery-marked coho is an important step toward reducing the pressure on wild stocks in the Strait of Georgia. The success of this restriction depends on the survival of released unmarked fish. The use of more fish-friendly nets and other harvest gear such as barbless hooks can result in lower fish mortality. Barbless hooks are now mandatory in the sport fishery to minimize damage to released fish.

- Focused monitoring and evaluation of enhanced as well as wild stocks can reveal trends that are often masked in unmonitored situations and compounded by the effects of mixed stock fishing. This information can help in the management of mixed stock fisheries, when combined with stock assessment analyses and with harvest reduction responses. A critical piece of information that is required is the full accounting of hatchery fish in catch and spawning escapements.

- Another fishery management approach to reduce the impacts of mixed-stock fisheries is to modify run timing of hatchery fish so they do not mix. Creation of a hatchery stock with different timing than the natural fish in the system could allow for hatchery stock-specific harvest to reduce or avoid mixed stock problems.

A problem related to some of these measures dealing with mixed-stock fishing is that they do not address other issues associated with ecological or genetic interactions. For example, the development of mass-marked selective fisheries for hatchery fish does not address concerns regarding the ecological effects of large numbers of hatchery fish. Further, if selective fisheries prove to be successful, they could generate demands for increased hatchery releases, increasing the potential for other types of negative interactions.

Measures that have been developed to reduce genetic interaction:

- The choice of broodstock has least damaging genetic impacts if it incorporates representation of natural populations native or adapted to watersheds in which hatchery fish will be released (NPPC 2003 p.A-3). Rather than transplanting stocks, local broodstock should be used to establish the enhanced groups. Transfer and use of non-local broodstock in Canadian hatcheries is reviewed by the joint Federal-Provincial Introductions and Transfers Committee. The committee reviews transfers from the perspective of ecological, genetic and disease risks and licences only those transfers where risks are considered to be minimal.

- Use of as many spawners as possible may be "the single most important strategy" for minimizing inbreeding effects and maintaining genetic diversity within the enhanced population. A suggested minimum effective breeding population is 100 spawning pairs – except when rebuilding a historically small stock, in which case 25-100 pairs is the recommended minimum, and when rebuilding an extremely depressed stock, in which case a Stock Recovery Plan is recommended. (Extremely depressed stock is defined as less than 100 spawners, and below 5-20% of historic escapement. The effective breeding population is based on the number of parents used within one spawning year, whereas the effective population size is estimated as the effective breeding population times the average generation length of the species (Waples 1990b)). In a recent U.S. report, another recommendation is that broodstock should be sufficient in number to maintain effective population size of 1000 fish per generation, collected and held so as to achieve less than 10% pre-spawning mortality, collected to minimize founder effects, with representative samples of fitness-related components (NPPC 2003 p.A-3,4).

- Use of local sources only for brood stocks and rearing helps reduce straying.

- Certain release practices also reduce straying and there are techniques to improve homing, such as imprinting to scents and on-site rearing and release. For example, in the Nicola River smolt imprinting ponds have been used to encourage homing.

- Spawning guidelines dictate protocols for mating and fertilization methodology in relation to the number of fish to be spawned.

- Collection of representative samples with respect to size, age, sex ratio, run, spawn timing and other traits important to long-run fitness is important. Collection is most effective in avoiding genetic damage if it avoids the use of stocks from outside the watershed (NPPC 2003 p.A-3,4).
- There is an essential need to monitor genetic traits over time (NPPC 2003 p. A-3,4).

Measures that have been developed to avoid or reduce competition:

- Fish releases are most appropriate if they take place at optimum time and size, as determined by site-specific survival study, in numbers that do not exceed carrying capacity for the natural population (NPPC 2003 p.A-10).
- It is best to produce fish that are qualitatively similar to natural fish in physiological status, behaviour and growth rate, and to release them at sizes and life history stages similar to those of natural fish of the same species (NPPC 2003 p.A-10).
- In order to avoid competition, most facilities rear stream rearing species to the smolt stage and do not release fed fry. Although some projects released fed fry in the 1980s and 1990s, this is now done only at a few sites which have under-utilized or barren habitat.
- If there is a probability of a capacity bottleneck in the estuary, hatchery fish may be released at a different time than wild.

It is becoming increasingly important to take into account both freshwater and marine carrying capacity in the sizing of hatchery programs. Salmon releases should be regularly adjusted to the carrying capacity of the coastal and ocean feeding areas in an international context. However, researchers acknowledge that the science for estimating carrying capacity is in its infancy and that there is insufficient information on which to develop strategies for adjusting hatchery release numbers to changes in ocean carrying capacity. Sweeting et al. (2003), though acknowledging the lack of understanding and information, recommended the following: "… any enhancement program requires clear policies to be in place for both the wild and the enhanced stocks. Furthermore, these policies should not only include limits to the production of Pacific salmon in marine ecosystems, but also provisions to vary production according to prevailing ocean conditions. Successful management of Pacific salmon … must recognize that the numbers of wild Pacific salmon that return to spawn (escapement) is a function of wild and hatchery production, of ocean carrying capacity, and of fishing rates." (Sweeting et al. 2003 p.500) With the recent regime shift to increased ocean productivity, it will be important to assess whether there is still over-production of salmon relative to marine carrying capacity. The implication of Sweeting's statement is that hatchery release levels could be adjusted depending on the expected production regime in the ocean. If hatchery and wild fish do compete in the ocean then during poor ocean productivity periods, hatchery releases should be reduced to assist the maintenance of wild populations by reducing competition in the marine environment.

Measures that have been developed to reduce the effects of predation:

- Reduce numbers of predators through culling (e.g. shooting seals).
- Include predator training and supplemental feeding with natural prey items in the rearing strategies (see, for example, Maynard and Flagg 2001 and Berejikian et al. 2001).
- Insure that fish are migration-ready when released.
- Where possible, release fry at night during periods of high water/turbidity/velocity to avoid visual predators.

- Avoid release of large numbers of smolts in areas with high concentrations of wild fish: decrease the number of smolts released; and use a volitional release strategy or a strategy that employs smaller release groups spread temporally (Nickelson 2003 p.1054).

Measures that have been developed to reduce the spread of disease:

- Some measures to improve fish health of enhanced stock are taken at the stage of broodstock selection:
    - Broodstock selection should represent natural populations native or adapted to watersheds in which they will be released, with pathogen history indicating no threat to other populations in the watershed (NPPC 2003 p.A-3).
    - Disease screening is used to avoid diseased brood stock (e.g. Rivers-Smith sockeye restoration (Hilland et al. 2001).
- Several measures that may reduce the spread of disease from enhanced salmon to wild salmon are taken at the facility (if released fish are healthier, they are less likely to spread disease to wild fish):
    - Low density rearing with observance of water quality and temperature standards ("adult holding standards") helps maintain fish health in facilities (NPPC 2003 p.A-4). Use of the correct amount and type of food to achieve desired growth rate and desired condition can also help (NPPC 2003 p.A-8-9).
    - Careful hygiene should lower the risk of disease spread within a facility. Disease protocols (guidelines) such as disinfection procedures, if followed, should minimize the risk of spread of disease to wild fish as well as within enhancement facilities.
    - Fish in the hatchery can be and are treated to control disease.
- Since facility effluent water may carry pathogens into local streams or rivers, the quality of water discharged from the facility as well as the quality of the water within it should be monitored.
- In general, observance of fish health inspection standards such as (in the U.S.) Integrated Hatchery Operations Team (IHOT) and Pacific Northwest Fish Health Protection Committee is important. In B.C., fish health management plans and related guidelines address feeding and handling practices, health monitoring, effluent management, and disease screening. Guidelines prescribe containment practices in the event of disease. Protocols exist for management of pathogens and treatment, involving the Fish Pathology Program.

8.3 Hatchery reforms dealing with wild stock interactions

In this section, we discuss some of the more recent and comprehensive hatchery reform efforts, as they pertain to wild stock-enhanced stock interactions, and with an eye to applying the reform experience to the B.C. situation. In the case of the hatchery reform efforts chronicled here, when all is said and done, much more has been said than done.

A pattern of lack of action on recommendations

There are many more examples of good ideas presented for reform than there are of effective reform taking place on the ground and in the water. This suggests that inherent – maybe insurmountable – institutional, political and budgetary obstacles exist, which need to be analyzed and addressed as well as the technical suggestions themselves. There seems to be a major disconnect, in other words, between proposals and actions implemented. Some of these proposals are described below.

- In B.C., many pages of public testimony, offered at the beginning of the Salmonid Enhancement Program in the early and mid-1970s, pointed out many of the same problems, risks and cautions that we point out in this report. Testifiers from many stakeholder groups and many areas of the province called for flexible, small scale, participatory solutions to salmon enhancement. (Fisheries and Marine Service Canada 1977 and 1978). The subsequent "big hatchery" orientation of SEP proceeded in spite of these cautionary comments. A subsequent "SEP Update" consultation review in 1978 reiterated many of these same points, and seems to again have been largely ignored (Fisheries and Oceans Canada 1979).
- A 1993 SEP program review included many of the same recommendations for comprehensive reform that have been highly praised in the recent Washington State hatchery reform effort. They seem to have been implemented partially and piecemeal in the B.C. setting (ARA Consulting Group 1993).
- A 2001 SFU conference on The Future of Hatcheries came up with a number of recommendations for reform of the B.C. situation, and called for a small committee of attendees "to pursue this vitally important objective." As of December 2003, that committee has not been appointed; no apparent follow-through from that meeting has taken place (Routledge 2002).
- Even the highly-touted Washington State reform program now finds its funding threatened, as cutbacks in federal funds may take place.

In the U.S., commentators have questioned even the integrity of the intent of the reform process. For example, journalist Rebecca Clarren suggested that

> *"……..many fish biologists and conservationists believe these reforms are simply a way for (U.S.) state and federal agencies to feed off the salmon cash cow and to perpetuate the myth that we can have healthy salmon populations without restricting the number of fish we harvest or restoring habitat."*

Clarren quoted Joe Whitworth, executive director of Oregon Trout:

> *"We're just putting a smiley face on what we want to do, (which is to use hatcheries) the way we've always done it. It will take years for the agencies and the fishing-dependent citizens to wean themselves from the hatchery narcotic." (Clarren 2002).*

In such an environment, it seems critical to have independent auditing capability to monitor and evaluate record-keeping and performance of facilities large and small. (The need for independent auditing and reform has been noted in the United States by Goodman (1990)). However, in the current – and anticipated future – climate of DFO funding cutbacks and shortages, that level of scrutiny appears unlikely. All projects are required to report what they have done, including the adults and eggs collected, and juveniles released. However, audits of adherence to guidelines are not done.

In each of the hatchery reform efforts discussed below, the availability of current, relevant and precise data seems to have been a critical success factor. The subject matter is complex; changes and performance levels should be readily identifiable. However, we also note that some efforts are handicapped by lack of data, or by the unwillingness of involved parties to have their operations closely or meaningfully monitored.

In the case of the two major American hatchery reform reviews described below, there are funding transition issues. Much of funding for the Washington and Columbia Basin hatchery reviews has come from the U.S. federal government; however, it is anticipated that funding for ongoing changes in operations and monitoring of performance will in the future have to come from a variety of sources.

Hatchery Reform in the Northwest: Oregon Trout Report (1996)

This report (White et al. 1996), prepared for the organization Oregon Trout, served the valuable function of collecting in one place the findings from 950 articles which report on, or mention, problems caused by artificial fish propagation and stock. The literature review included nearly every key North American article since 1900. This collection has provided part of the foundation for comprehensive, multi-component programs such as those described below. A summary of the general conclusions reached by these authors is available at:
www.ortrout.org/for/hatcheryreform.htm

Recent Developments from Washington State and the Columbia River Basin

The Washington State Hatchery Scientific Review Group (HSRG) and the Northwest Power and Conservation Council (NPPC) Columbia River Basin Artificial Production Review and Evaluation (APRE) hatchery reform efforts have provided a set of documents and templates which represent the state of the art in hatchery management and analysis and evaluation of hatchery operations. The two processes have incorporated the comments and experience of approximately 200 fisheries experts in their Operating Guidelines documents. The HSRG and NPCC guidelines in turn drew from the NOAA Fisheries Hatchery Genetic Management Plans (HGMPs) (NOAA 2002), which are used to determine compliance with the U.S. Endangered Species Act. In addition, they drew upon earlier work of NMFS and NOAA researchers (Flagg and Nash 1999).

Washington State Hatchery Reform Program (1999-present)

Washington State's recently-instituted hatchery reform program for Puget Sound and coastal Washington is one of the more comprehensive and well-documented of the current generation of hatchery reform programs. (For full details and numerous background papers, reports and publications, see Long Live the Kings (2003).)

The program began in 1999, and deals with the approximately 100 hatchery facilities in Puget Sound and coastal Washington. The program is funded by state ($8 million) and federal governments ($12.6 million over three years). It balances independent scientific information (including one Canadian representative, Dr. Trevor Evelyn), support from elected and appointed officials and government policy makers, with independent third-party project management (Blankenship 2002).

Its initial years of activity have been devoted to establishing general principles and scientific tools that are intended to guide all reform analyses and proposals. In addition, the team has developed criteria for region-by-region review for ten identified regions within its study area, so that the analysis is not a "one size fits all" exercise (Hopper 2002).

The team expects to have reviewed the history and goals of all hatcheries in all regions, and to have assessed the status of stocks and habitat, by the end of 2003. Recommendations for changes in operations are first presented to hatchery managers in draft form, before they are finalized. To date, only one hatchery has been closed, but operating practices have been changed in more than 20. The program's scientific review panel issued 218 recommendations to state and tribal fisheries managers (McClure 2002).

Northwest Power and Conservation Council: Columbia Basin Artificial Production Review and Evaluation (1997-2003)

Another recent and comprehensive hatchery reform program is that developed by the Northwest Power and Conservation Council for the approximately 150 hatcheries and associated facilities under its jurisdiction in the Columbia River Basin in Washington, Oregon, Idaho and Montana. The Council oversees electric power systems and wildlife recovery in the Columbia Basin.

Artificial production programs now produce the majority of salmon and steelhead that return to the Columbia River. Annual releases in recent years had grown to more than 200 million juveniles, though production had been reduced to 142.5 million fish by 1999.

This review program, entitled the "Artificial Production Review and Evaluation (APRE)," was created in response to a 1997 directive from the U.S. Congress. It has issued a number of program documents in recent years. Its most recent and most comprehensive final report was issued in October 2003 (NPCC 2003). The new standards for hatchery management being promulgated by NPPC would require that managers demonstrate that their stocks are not harming wild fish. It was initially proposed that detailed new performance standards be used to determine which hatcheries would be funded. However, after outcry from those whose performance was to have been evaluated, it appears that the standards have been at least temporarily shelved. The APRE analysis began with a review of the scientific basis of artificial production within the Columbia River basin as reported by Brannon et al. (1998).

The proposed standards, described in three detailed reports (NPCC 2000), called for collection of three types of information: specific details of fish culture practices inside the hatchery; what happens to hatchery fish after release, and what effect hatchery fish have on wild and other hatchery fish outside the hatchery (NPCC 2000 ISAB 2000-4). The drafters of the standards also noted that indicators should be organized hierarchically for sub-basin, province and basin – and that they should encompass and relate to the ten artificial production policies and five purposes of artificial production that had been outlined in the APRE. They pointed out that, for maximum effectiveness, the specific practices to be reformed should be identified, rather than just speaking about hatchery reform in the abstract.

State of Oregon: Hatchery Policy (2003)

The state of Oregon, through the Oregon Department of Fish and Wildlife, is currently drafting a state-wide hatchery policy. The policy will be subject to the state's already adopted (Nov. 2002) Native Fish Policy (which seems somewhat comparable to the Canadian Wild Salmon Policy in its coverage), and would incorporate federal salmon recovery goals under the Endangered Species Act. Oregon's Indian tribes are hatchery co-managers and are involved in development of the policy.

It is expected that the task force developing the hatchery policy will deal with some of the same issues that appear in B.C. hatchery discussions. These include: the need for a continuing strong role for volunteer organizations, economic and fiscal impacts of hatchery closures or production changes, funding options and marking strategies.

(O'Bryant 2003a, ODFW 2003). For additional background, see IMST 2000 and IMST 2001.

NOAA Fisheries Northwest – Salmon Recovery Division

NOAA Fisheries Salmon Recovery Division is working on a number of hatchery guidance documents as part of its ongoing artificial propagation policy. This federal agency works with the states of Oregon, Washington and Idaho and Indian tribes on such issues as: hatchery listing policy, articulating how hatcheries aid with the listing process under the ESA, guidance on hatchery design and day-to-day operations to maximize conservation activity, and performance measurement. (U.S. NMFS n.d.)These principles have recently been applied in an upper Columbia River steelhead recovery agreement in Washington State (O'Bryant 2003b).

8.4 Recent developments relevant to the future of enhancement

In recent years, new laws and policies have come into play that are relevant to the consideration of enhanced-wild salmon interaction. Other developments relevant to the future of enhancement include a recent public review of SEP, funding cutbacks, and changing technologies and operational guidelines.

See Appendix 3 for a chronology of salmon enhancement in B.C..

8.4.1 Recent legislation

U.S. Endangered Species Act

In the United States, the enactment of the Endangered Species Act (ESA) in 1967, and its strengthening in 1973, were primary drivers leading to more comprehensive use of conservation strategies in the operation of hatcheries and other forms of enhancement (U.S. Endangered Species Act, n.d.). In Washington State, for example, several Puget Sound and Coastal salmon and steelhead stocks are listed or proposed for listing under the ESA. The Northwest Power Conservation Council (NPCC) efforts in the Columbia Basin also use hatchery technology to support recovery of ESA listed stocks, following a 1999 National Marine Fisheries Service "Biological Opinion" that prescribed changes in facility operations that would take the form of so-called "Reasonable and Prudent Alternatives." The U.S. federal government has provided a brief explanation of the salmon recovery aspects of the ESA (US NMFS NOAA 2003).

Canada's Species at Risk Act

Canada's Species at Risk Act passed the Senate in late 2002 and came into force in 2003 (Government of Canada 2002). It calls for recovery plans or strategies to be pursued to preserve species that are endangered or at risk. In the case of wild salmon, these plans and strategies may include various forms of enhancement. It remains to be seen whether Canadian experience will be comparable to that in the U.S. Some observers (Boyd 2003) have commented that the Canadian Species at Risk Act is not as powerful as the American version.

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) is responsible for identifying species that are endangered or at risk. COSEWIC's listings provide the basis for plans and strategies that might be called for by the Act. Specific salmon runs can be listed by COSEWIC (Environment Canada 2003). DFO Coordinator for the Species at Risk Recovery Plan, Carol Eros, noted at the 2003 World Salmon Summit that "the Minister of Fisheries and Oceans has considerable responsibilities and accountabilities for survival and recovery of aquatic species-at-risk as well as their protection." She further noted that, although three endangered Pacific salmon populations have not yet been legally listed by SARA, recovery planning is currently underway.

Canada's Oceans Act

Canada passed the Oceans Act in 1996 (Government of Canada. 1996). It took effect in 1997. It seeks to achieve integrated, ecosystem-based management of the nation's ocean regions. Its national strategy, which was published in 2002, incorporates three inter-related components: sustainable development, the precautionary principle and integrated management. (Fisheries and Oceans Canada (DFO) 2002). The Minister of Fisheries and Oceans developed the national strategy in collaboration with provincial governments, First Nations organizations, and coastal communities. Implementation of the strategy had not begun as of the date of this writing.

8.4.2 DFO policies released in 1998-2000

A number of DFO policies released in 1998-2000 suggested a shifting focus for SEP. The policies emphasize conservation and restoration of salmon and salmon habitat, set priorities for the use of salmon, and promote more public involvement in decision-making on enhancement activities.

New direction for Pacific Region

A New Direction for Canada's Pacific Salmon Fisheries, released in October 1998 by Minister Anderson, set three priority policy areas: conservation, sustainable use and improved decision-making. Among 12 principles for managing the salmon resource, conservation of stocks was stated as the most important objective, with other priorities including selective fishing, First Nations traditional uses, and greater community involvement.

An allocation framework for Pacific salmon 1999-2005

Following on *A New Direction*, *An Allocation Framework for Pacific Salmon: 1999-2005* (December 1998) set out seven principles to guide salmon allocation decisions. The framework set priorities for the various fisheries (Aboriginal, recreational, commercial), encouraged selective fishing, and established annual coast-wide targets for the commercial sector.

A framework for habitat restoration and salmon enhancement

An intergovernmental Habitat Restoration and Salmon Enhancement Working Group proposed a policy to rationalize federal and provincial enhancement activities in light of new conservation priorities. Its report entitled *A Federal-Provincial Framework for Habitat Restoration and Salmon Enhancement in British Columbia* (September 1998) also recommended a process for conducting integrated watershed-based planning.

The Wild Salmon Policy

Canada's Wild Salmon Policy, which is being developed by DFO, is currently in draft stage. Drafts of the policy have been evolving since the year 2000. Earlier versions of the draft policy included, in two of its six principles, statements regarding the desirability of strategic use of enhancement strategies to help preserve and protect wild salmon:

- Principle five stated: "Salmon cultivation techniques may be used in strategic intervention to preserve populations at greatest risk of extirpation." (DFO 2000 p.20)
- Principle six stated: "For specified conservation units, when genetic diversity and long-term viability may be affected, conservation of wild salmon populations will take precedence over other production objectives involving cultivated salmon." (DFO 2000 p.21)

In the explanation of Principle 5 and 6, the draft policy noted a shift in focus away from production and towards rebuilding wild stocks. It is not known whether these principles have been retained in more recent drafts of the policy.

Consultations were held in B.C. in the summer of 2000 on the draft Wild Salmon Policy. Commitments to release the revised policy have been repeatedly delayed. To this date there has been no release of the revised policy.

8.4.3 Pacific Fisheries Adjustment and Restructuring Plan (PFAR).

In 1998, the Dept. of Fisheries and Oceans announced a multi-part plan aimed at restoring the health of Canada's fisheries on the Pacific Coast. One hundred million of the $400 million to be spent between 1998 and 2002 was allocated to a "Resource Rebuilding Strategy." Two of its four components, the Habitat Restoration and Salmon Enhancement Program (HRSEP) and the Pacific Salmon Endowment Fund (PSEF), related to hatcheries and enhancement.

Habitat Restoration and Salmon Enhancement Program (HRSEP)

The HRSEP was one component of the Resource Rebuilding Strategy. It was viewed as a continuation of SEP, with an increased emphasis on involvement of community stewardship groups. The budget for this program was estimated at $32 million for the five-year period. The program was terminated, as scheduled, in 2002.

A report on the program, issued in 2001, noted that many of the 100 projects funded by the program to that date were designed to improve weak coho stocks, through strategic stock enhancement (Fisheries and Oceans Canada (DFO) 2001).

Pacific Salmon Endowment Fund (PSEF)

Another component of PFAR was the proposed Pacific Salmon Endowment Fund (PSEF). This endowment was intended as a long-term fund to ensure a stable source of funding for projects developed by local stewardship groups. Initially proposed at the $100 million level, the Fund was established, at the $30 million level, in 2001. Thus, annual interest income would be roughly $825,000. The Pacific Salmon Foundation was designated program manager of the Fund and is engaged in raising additional funding and conducting salmon recovery projects in various areas of the province (Pacific Salmon Endowment Fund 2003). A group of Lower Fraser Area stewards noted, in the proceedings of its November 2002 Facing the Future meeting, that the PSEF funding did not replace the $13.5 million in federal funding that had been withdrawn with the closure of the HRSEP, a related habitat program (HCSP) and (at that time threatened) SEP reductions on the order of $3.5 million (Stewards of the Lower Fraser Area 2002).

8.4.4 Funding cutbacks

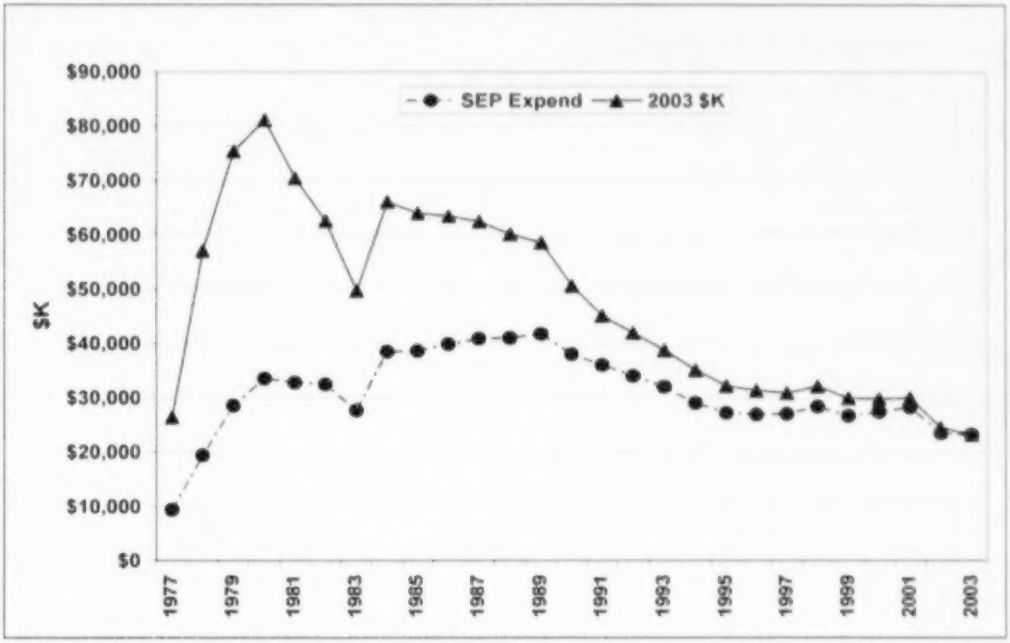
In analyzing trends in SEP funding, it is difficult to extend the early budget categories to the present because SEP has been integrated with the Habitat Branch and there have been a number of other changes in organization and responsibilities. However, the information presented in Figure 21 is considered a good estimate of overall enhancement related spending.

Trends in SEP funding

Figure 21 shows total SEP expenditures in current dollars (as spent) and in 2003 dollars (with allowance for inflation) since the beginning of the program in 1977. Total expenditures include construction, operations, studies, public involvement, and other costs. After the initial intensive capital expenditure, funding of that part of the program declined, while the operations and maintenance portions of the budget increased.

Figure 21: SEP expenditures from 1977 to 2003.

The values are in thousands of dollars. To provide an indication of the relative value of SEP actual expenditures, those expenditures in inflated 2003 dollars are also presented. (Source of data: SEP Annual Reports and other DFO financial reports. The 2003 dollars are from Bank of Canada website inflation calculator.)



In 1989, the total SEP budget was $41,761,000. From 1990 to 1998 there were budget reductions of $10,874,000 (approximately 29% of the budget). Since 1998 there have been further program cuts. The SEP budget in 2003 is $23,166,000, reflecting a further cut of 25% since 1998. Although the official budget was cut by approximately $3.5 million the spending initially stayed constant, made up from other sources.

To mitigate these reductions, significant savings have been achieved since 1990. For example, in major facility operations, efficiencies have been achieved by: changing fish feeds and feeding, entering into operational partnerships, staff reductions, automation and deferring maintenance. Clearly, measures such as deferring maintenance can only bring short-term savings, possibly increasing costs in the longer term.

Relative emphasis on various SEP programs

From the outset, hatcheries have consumed most of DFO's salmonid enhancement budget. Figure 22 shows the spending on operational activities (operations, maintenance, lake enrichment, CDP and public involvement) and studies (management, environmental, assessment, research).

Figure 22: SEP spending on operations (Ops) as compared to spending on studies.

The values are in thousands of dollars. The SEP spending on project operations and studies are compared in actual and 2003 inflated dollars from 1977 to 1989. The information beyond 1989 is not available. (Source of data: SEP Annual Reports. The 2003 dollars are from Bank of Canada website inflation calculator.)

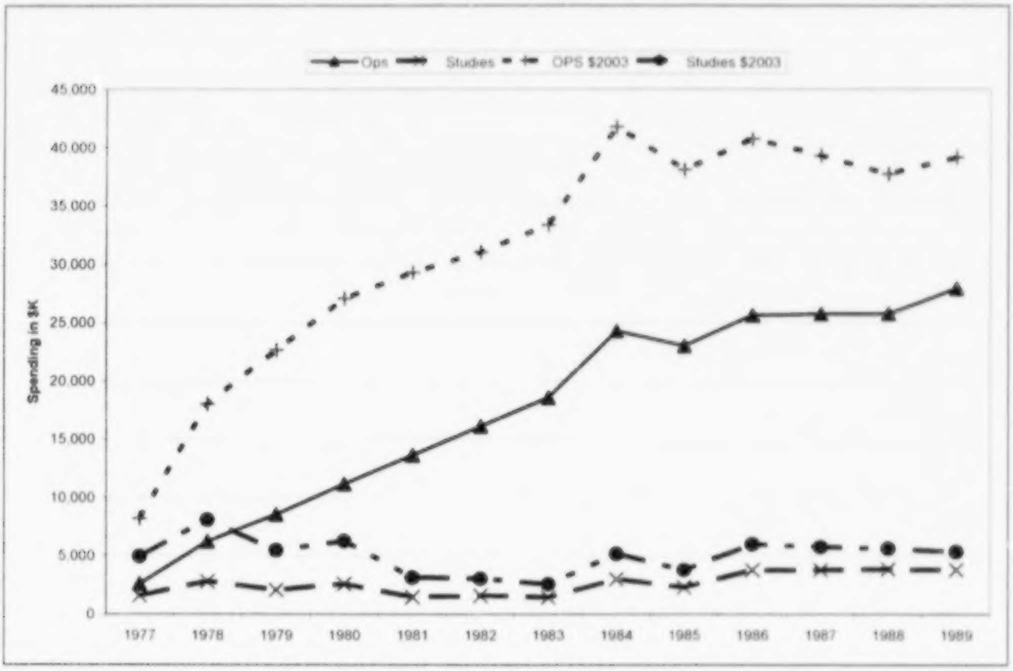
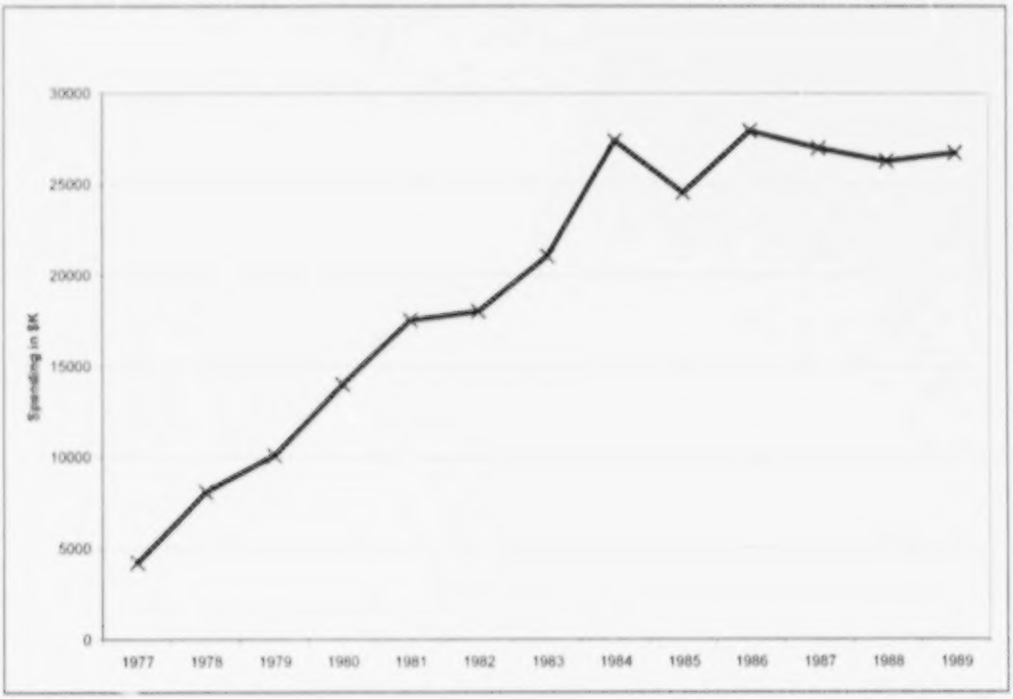


Figure 22 shows that SEP operational activities were costing about $40,000,000 ($2003) per year from 1984 to 1989. Figure 23 shows just Operations and Maintenance spending in $2003. The SEP annual operations and maintenance budget increased as more projects were brought into operations. After 1984, the budget plateaued at about $47 million because few new major facilities were added. This is more than the total SEP spending in 2003, and yet there are still community development, public involvement, resource restoration, and other programs. As most of the 1980s facilities are still being operated, clearly there must have been major efficiencies in operations and/or cuts in assessment-related activities. Lake enrichment operations and evaluation have been reduced to a remnant program and costs.

Figure 23: Operations and maintenance expenditures in $2003.

Source of data: SEP Annual Reports. The 2003 dollars are from Bank of Canada website inflation calculator.



The budget reductions from 1990 to 1998 included headquarters and support reductions, facility closures, and reduced production, detailed below.

$7,112,000 in SEP Headquarters and Support Reductions, including:

- $1,057,000 for project assessment and research
- $129,000 for program coordination and information management
- $578,000 for habitat restoration
- $718,000 for capital maintenance and equipment
- $1,558,000 for new capital development

$1,916,000 in facility closures, including

- Whitehorse, Birkenhead, Clearwater, Eagle and Quesnel DFO hatcheries,
- Chehalis, Kitsumkalum, Terrace, Oweekeno, Skidegate, Necoslie, and Kispiox CEDP facilities

$1,847,000 in reduced production, including:

- reduced CEDP production;
- spawning channels (Orford, Kakweiken, Glendale, Nekite and Phillips);
- trout production;

- Burrard Inlet chinook sea pens;
- Upper Adams sockeye project;
- production from major facilities; and
- Chilko Lake fertilization.

Although the places closed, including unmanned channels, were closed because they were the least effective in meeting SEP objectives, they also tended to be the least economically efficient projects. Many of the CEDP projects closed had very high social and First Nation benefits but low economic and production performance. It is unclear what impact the closures had on conservation and provision of information.

9. THE STATE OF THE KNOWLEDGE BASE

As explained in Section 8.1, the current knowledge base does not permit a definitive assessment of the risks that enhancement poses to wild salmon, or even of the effectiveness of enhancement in broader terms. General research challenges (Section 9.1) are reflected in specific gaps in our understanding of the various forms of interaction (Section 9.2). The significant deficiencies in knowledge described in this section do not, however, preclude informed estimates of the risks posed to wild salmon by enhancement – these are provided in Section 10.

More emphasis in the assessment or evaluation of enhancement needs to be given to the interactions between enhanced and wild salmon production (Riddell 1993a p.350). There is a need for research that will promote better understanding of the effects of enhancement on wild salmon (Perry 1995 p.159-160).

> *"The biggest gap in our knowledge is understanding the performance of hatchery-produced fish and their progeny in the natural environment. Can release programs, particularly those designed for conservation, provide a net long-term benefit to natural populations? ... Ideally, evaluations of supplementation programs should be conducted over a number of generations to permit distinguishing ecological and genetic effects of fish culture, and to evaluate the effectiveness of natural selection to restore fitness in natural populations of mixed hatchery-wild ancestry." (Fleming and Petersson 2001)*

9.1 General research challenges

There are at least three general challenges that increase the difficulty of conducting research to better understand the interactions of enhancement with wild salmon: experimental design, lack of basic information and data, and difficulties in understanding stocks and populations.

9.1.1 Research challenge: Experimental design

There are competing hypotheses regarding the role of enhancement in the decline of wild Pacific salmon. Testing and resolution of discrepancies between these hypotheses can only take place through a process of rigorous experimentation that is purposefully designed to explore the interactions between enhanced and wild salmon. One experiment will not be enough. There are so many sources of variability in the environment that some replicates will have to be planned, over space, and over the years. This will dramatically increase the scope, complexity and cost of such work. For example, if experiments were conducted on a two years on, two years off basis, climate regime change and other, shorter-term environmental factors will complicate the experiments. These environmental factors do need to be taken into account – they cannot be assumed to be either random or constant. (See also Section 9.3.)

"Enhancement programmes are an intervention into biological communities and each programme should be treated as largely experimental." (Riddell 1993a p.348) Clear research questions are required in order to determine what to measure and how.

What kind of experiments do we need? Many scientists agree that to understand the interactions between enhancement and wild salmon we need large-scale experiments:

> *"the most valuable research is likely going to require large-scale interventions in the production of juvenile salmon with possible effects, at least in the short term, on adult returns." (Perry 1995 p.160)*

> *"Some critical issues (e.g., domestication selection, relative importance of inbreeding depression and outbreeding depression) are regularly identified by*

> *scientific workshops and panels as high-priority research topics; however, such research is seldom funded because the necessary experiments are expensive, time-consuming (often requiring several fish generations), and logistically difficult." (Waples 1999 p.20)*
>
> *"Determining whether released fish add to or simply replace the natural productivity of wild fish "is extremely important, but difficult, requiring an experimental design that incorporates manipulations (i.e. adding hatchery fish) and controls (i.e. excluding hatchery fish) on both spatial and temporal scales. Such experiments are expensive, long term and require management vision ..." (Fleming and Petersson 2001).*

In addition to these demands for large scale and long term studies, good experimental design calls for "controls." These are examples in places and times that are likely not influenced by the factors of concern yet are comparable with examples where changes might be expected (i.e. "the experimental system"). Variability in the natural environment and among enhancement projects makes the establishment of the controls difficult. For example, it is difficult to determine whether there is more variability from stream to stream or from brood year to brood year. Every facility and every location is different. The uniqueness of each site and the lack of common applications makes finding a representative sample difficult (Riddell 1993a).

It is not easy to have test and control groups for a particular habitat area (e.g., stream or estuary) within a given production year. The greater the variation, the more pairs of streams (control and experiment) and the more generations of fish may need to be studied. "Further, the variability in production may increase as the numbers of enhanced fish released increase." (McCarl and Rettig 1983, and Fagen and Smoker 1989 in Riddell 1993a p.348) "As fish production from enhancement increases, the quality of the data will fall unless fish marking for assessment purposes is similarly increased." (Coho Steering Committee 1992 p.34)

9.1.2 Research challenge: Lack of basic information and data

There are major gaps in our understanding of most of the key processes associated with fish culture (Waples 1999 p.20). For example, some issues critical to the understanding of genetic interactions, such as domestication selection, have not received sufficient research investment. Extensive fish production and treatment related information is collected for enhanced stocks, but very little for wild stocks with which they interact. While SEP has invested significantly in regional assessments of production from enhancement over the years, these have focused on returns. Little attention has been paid to wild stocks. For example, there is little information on straying rates of enhanced fish or on survival of progeny of enhanced fish that spawn in the wild. These information shortfalls limit our ability to assess the impacts of enhancement on wild salmon.

The basic problem is lack of a long-term commitment to assessment and to the integration of hatchery and wild information. Assessment programs need to identify the data needed and monitor to collect that data. (See also Section 8.1.)

9.1.3 Research challenge: Difficulties in defining stocks and populations

One of the basic issues in salmon assessment and management is the definition of, or ability to distinguish between, stocks or populations. To mitigate most negative interactions managers must be able to distinguish genetically-distinct groups of fish. Yet it is debatable whether populations classified as a single stock are definitely a single stock (Wood 2002 p.8). As a general rule, the larger the distance between animals, the more genetically distinct they become, but spatial and temporal variability pose challenges (Riddell 1993b). Discontinuities are caused by such factors as geography, temperature and spawning regimes. Given there are no clear boundaries, genetics cannot always serve as a method for differentiating stocks.

The problem is about the amount and distance of straying of wild and enhanced populations. If these strays cannot be distinguished from local, wild salmon then assessing interactions of enhanced and wild stock is not possible. In particular, the degree to which effects are localized (one local population or stream as opposed to many) cannot be established.

9.2 Knowledge gaps and research challenges regarding interactions between enhancement and wild salmon

The general research challenges described above indicate that the scope of what we don't know about interactions between enhancement and wild salmon is large. Referring back to the forms of interaction explored in Section 7, some specific examples of knowledge gaps, key research challenges, and some proposals for studies are listed here.

9.2.1 Knowledge gaps: Mixed stock fishery interactions

Major gaps in our understanding of mixed stock fishery interactions include limited ability to identify enhanced and wild populations in the fishing area, and limited data on relative harvest rates. In many fisheries the mix of populations and species changes throughout the fishing season, with variations in abundance and migration timing, rate and route. This means that continuous sampling would be required to monitor the effect of a fishery on multiple stocks, and that sequential harvesting of a population through fisheries will result in changes in the relative abundance of populations. While species and stocks within species present maybe sampled through fisheries, our ability to differentiate hatchery and wild fish from one stock is particularly challenging.

The switch to mass marking to facilitate marked-only coho fisheries makes selective harvesting of hatchery-produced fish possible. However, it also results in losses of information from coded wire tagging (CWT); an important tool for following fish through their life and measuring survivals, straying, migration routes and timing, and fishing rates. Although few wild stocks are marked with CWTs, loss of this tool would limit our potential to better understand interactions of wild and enhanced salmon. DNA and other bio-marks are generally expensive, so with budget reductions are not a likely candidate to replace CWTs.

An example of this challenge would be managing coho salmon in the Strait of Georgia. Coho salmon abundance in the Strait is a mixture of many natural populations plus production from several large hatcheries in Canada and the United States. Before the mid-1990s, fisheries responded to the total abundance of coho and large catches frequently resulted. These catches resulted in fishing impacts that could not be sustained by the natural populations. Coded-wire tagging of hatchery fish and some wild stocks (i.e., coho indicator stocks) provided information on marine survival and fishing rates that allowed development of a management plan for the Strait. However, in the future, data collected on mass-marked and coded-wire tagged hatchery fish will no longer be representative of fishing impacts on naturally produced (i.e., unmarked) coho salmon. Changes in the number of spawners in natural populations may result from changes in survival rates and/or fishing impacts, but the cause of the change could no longer be examined through direct observations. As chinook salmon have a much more complex multiple age-structure than coho, they are marked with CWT and not mass marked.

9.2.2 Knowledge gaps: Genetic interactions

We can now measure genetic changes directly through genetic markers (e.g. DNA parentage analysis). This has reduced the problem of portioning genetic from environmental impacts on salmon.

The key questions that research on genetic interactions has yet to answer are:

1. Is there a long-term impact from enhancement that is reducing how well adapted a wild populations is to its environment?
2. If there is a long-term genetic effect, what is the relative genetic fitness of hatchery fish spawning in the wild?
3. If genetic change is occurring in the enhanced populations, how quickly does genetic change occur and how quickly does it disappear in the wild?
4. What is the frequency and distribution of hatchery fish that stray into natural populations, and how effective is the exchange of genes between these populations?

Other commentary on knowledge gaps and research needs related to genetic interactions is as follows:

- It has been extremely difficult to demonstrate reproductive impairment of hatchery fish crossed with hatchery fish or hatchery fish crossed with wild cross fish under wild conditions, since we would need to not only show whether such spawnings had been immediately successful but also whether the juveniles produced by such matings had normal survival rates (Walters and Martell, in press).
- "... we need an estimation of lifetime reproductive success, adult to adult, over the whole lifecycle. This is our best measure of fitness. We need it to assess multiple generations in natural habitats, comparing fish from a common ancestry. We need to identify the major components of fitness; in other words, which are the behavioral, morphological, physiological aspects of these fish that are most important in determining their fitness in the wild? ... We need to characterize how fish adapt to the wild and to the hatchery. Are they fundamentally different...? We need to determine whether domestication is reversible and if so, what sort of time frame are we talking about?" (Hard 2002 p.83)
- "At what level should we manage fish? Do we have the genetic tools to determine how many genodemes [small very localized groups of spawning salmon] we have within a stream? Even within some systems you have a range of life histories: some coho migrate out immediately whereas some stay within the tributaries. Natural selection must act quite differently on these two populations, and therefore there could be quite different genomes although they spawn within the same small spatial area." (DFO fisheries scientist)
- The rate of straying from enhancement facilities needs to be evaluated to assess the rate of genetic exchange. Yet straying can vary widely between hatcheries and between populations of wild salmon. Waples (1999 p.17) suggests that studies of straying have not resolved whether hatchery fish stray more than natural fish on average. Furthermore, homing and straying are complex phenomena that are not perfectly understood.

9.2.3 Knowledge gaps: Competition and predation interactions

Competition and predation are complexes of behaviors that are difficult to measure and their expression frequently depends on environmental conditions. Both types of interactions may be density dependent (i.e., the expression of these behaviours varies with the abundance of fish in the habitat). Discussion of them is frequently related to the carrying capacity of freshwater or marine environments, or the total number (or biomass) of animals that the environment can support. However, carrying capacity is an equally difficult concept to estimate and is not usually a stable value, even in the same habitat over time. Further, direct evidence for enhancement programs causing enhanced and natural fish to exceed rearing capacities of habitat has been difficult to collect. Therefore, concerns around competition are, "at present, largely based on inferences ..." (Riddell 1993a p.349). It is notable however that there is accumulating evidence for competition in open ocean ecosystems and between species (Ruggerone et al. 2003) and enhanced and wild production (Hilborn and Eggars 2001, Wertheimer et al.2002, Sweeting 2003).

There is also no clear understanding of the impact of the changing abundance of one species relative to other, whether wild or enhanced, in an environment with a limited carrying capacity. DFO considered exploring whether enhancement is causing density-dependent mortality by alternating hatchery production from 50% to 100% of the Strait of Georgia hatchery releases. "If there is no density-dependent mortality, survival should vary independent of smolt numbers, and adult returns will be lower on average for small year-classes." (Perry 1995 p.159) However, for chinook salmon a conclusive experiment may require 20-30 years, and for coho, 5-10 years. The experiment was never conducted largely due to the major reduction in marine survival of coho and chinook salmon during the mid-1990s.

Other commentary on knowledge gaps and research needs related to competition and predation interactions is as follows:

- Factors that affect competitive ability have been studied more than direct tests of competition: "We are aware of only two published studies that used substitutive experimental designs in which density was held equal among treatments, thereby testing for differences in competitive ability. Additional substitutive experiments will help managers to better understand the ecological risk of stocking hatchery fish." (Weber and Fausch 2003 p.1018).
- "Measuring predation in natural environments is very difficult, and most attempts at it yield inconclusive results." (White et al. 1996 p.23).
- There has been a relatively large amount of research on competition and predation between juvenile coho in streams. Yet few direct studies of competition in natural streams have been published, and extrapolations are usually drawn from laboratory experiments after studying a few component behaviors in the wild (White et al. 1996 p.23).
- The productive capacity of the Georgia Strait has not been adequately assessed for the various salmon species. "... studies of the carrying capacity of estuarine and marine survival and growth in the Strait of Georgia should be conducted to evaluate whether the marine carrying capacity is being taxed." (Coho Steering Committee 1992 p.35)
- We generally do not know precisely where in the juvenile life of fishes the density dependence that we see in overall recruitment has actually occurred. (Walters and Martell, in press). It is not necessarily as simple as assuming that density-dependent effects drop off over time as juveniles grow and can better avoid predation risk while foraging.

9.2.4 Knowledge gaps: Fish health interactions

There is very little information available on the incidence of disease in wild populations, so it is almost impossible to know whether it is higher or lower in wild fish exposed to hatchery fish. If new diseases did appear in wild populations, it may be uncertain whether these are endemic diseases that have simply never been observed before or an exotic disease introduced to the population. But, when an exotic disease is spread, as with whirling disease in the U.S., other means of spread such as boats or aquaculture may be difficult to distinguish from an effect related to transfer among hatcheries.

While the transmission of disease is certainly possible, three comments that refer specifically to this issue accurately summarize current opinion:

- "Although several pathogens are abundant and cause chronic problems in Pacific salmon hatcheries, little or no direct evidence exists of transfer from cultured to natural populations in spite of apparently widespread opportunities for this to occur." (Waples 1999 p.17).
- "The effects of disease on hatchery fish and their interaction with wild fish are not well understood." (Northwest Fisheries Science Center 2003).
- "… the magnitude of the problem [disease transfer to wild salmon] is difficult to quantify because the disease agents of concern are widespread in both wild and hatchery Pacific salmon as well as a number of non-salmonid hosts." (Noakes et al. 2000 p 363)

Results reported by Sweeting et al. (2003) indicate replacement of Georgia Strait coho by hatchery fish has occurred, but the mechanism that cause that replacement are not understood.

9.3 Information to put enhancement in context

Enhancement programs and especially hatcheries do not exist in isolation from the wild: they are linked to the natural environment and require a comprehensive program to evaluate. Not only do effects beyond the hatchery need to be taken into account, but interactions in freshwater and marine environments need to be examined in light of other pressures that the wild salmon are under. Many factors affect the survival and long-term viability of salmon, from harvesting to habitat degradation to climate change. The impacts of these factors, and of enhancement, have not been monitored adequately to distinguish their effects.

To address current assessment weaknesses, more monitoring of wild salmon populations and their habitat is required as a complement to enhancement information. The index streams and/or index populations approach would provide detailed information to better understand and assess factors affecting natural populations and how to best manage enhancements. Research leading to improved understanding of regime shifts could similarly improve management in relation to ocean survival. An "Ocean Productivity Index" could be developed and integrated into fisheries management plans to help managers adjust hatchery releases downward as regime shifts occur that will reduce marine carrying capacity (Flagg and Nash 1999).

10. CONCLUSIONS AND GUIDING PRINCIPLES: THE IMPACTS OF ENHANCEMENT ON WILD SALMON

In this last section of the report we review the risks to wild salmon as far as they can be understood at present and we draw some conclusions and provide guiding principles for future actions.

10.1 Relative impacts from different methods of enhancement

The impacts on wild salmon related to six forms of interaction were explored in Section 7 of the report. Here, the impacts are reviewed with reference to the categories of enhancement methods described in Section 6:

- obstruction removal (increased access to natural habitat)
- improved or restored natural habitat
- lake and stream enrichment
- channels (artificial habitat with natural spawning and rearing)
- human controlled spawning
- human controlled rearing
- hatcheries (human controlled spawning and rearing)

The first three types of enhancement have similar potential impacts and are discussed together. They do not involve artificial habitat – rather they increase access to habitat or they restore or improve the productivity of natural habitat. Given our definition of wild salmon as offspring of salmon that have bred and reared in the wild, these forms of enhancement only involve wild salmon (although it could be argued that lake and stream enrichment create artificial habitats).

The last four types of enhancement listed above all involve artificial habitat, and thus create cultured salmon which may differ from wild salmon. Of these four, channels are the least interventionist in the salmon life cycle, involving no human control over spawning or rearing. Channels can nevertheless have major effects in some cases, such as the large Weaver Creek and Babine Channels.

The impacts of human controlled spawning and human controlled rearing combine in hatcheries, so the impacts of these technologies are discussed together.

Overall, major hatcheries and large channels have the most significant of all the possible negative effects of enhancement on wild salmon.

10.1.1 Key interactions with wild salmon related to habitat enhancement (increased access through obstruction removal, restoration or lake/stream enrichment)

Habitat enhancement has the goal of assisting wild salmon rather than producing cultured salmon, so impacts on wild salmon are generally positive. Increasing access to habitat, or improving habitat by restoring or enriching it, increases productivity in the ecosystems involved, if successful. The dominant effect is either to provide new habitat, or to raise the carrying capacity of existing habitat. For example, enhancement may increase areas for spawning and rearing and may indirectly enrich the environment due to the contribution of more carcasses.

Mixed stock fisheries interactions: New or larger stocks of salmon may result from habitat enhancement, which may then require management in mixed stock fisheries, but all the stocks involved are wild.

Genetic interactions: The salmon that benefit from habitat enhancement are still subject to the selection pressures of the natural environment. Therefore, none of the changes resulting from habitat enhancement should lead to significant genetic impacts. The only area of (arguably) negative impacts could be that "improvement" of habitat may relieve certain selection pressures – e.g., easier passage upstream may allow for survival of smaller spawners; expanded freshwater rearing habitat may alleviate competition, allowing weaker fish to survive; and temperature control may alleviate temperature stress, lessening selection for temperature tolerance. On the whole, it is assumed that selection pressures continue to operate at levels within and outside the enhanced environments at sufficiently high levels to maintain fitness and genetic diversity in salmon populations.

Ecological interactions (including predation and competition): If the scale of increased production and/or survival is large enough, there can be significant interactions with stocks from systems without such enhancement. Interactions could include competition for food or rearing space and changes in predator-prey relations. Even within the stocks from the enhanced systems, ecological dynamics may change. And the increased numbers of salmon may also affect other species of fish, and predator and prey species. However, these post-enhancement ecological interactions are similar to changes that could occur without human intervention, and in many cases are restoring natural integrity to a system that has been impacted by human activities. In any case, ecological imbalances caused by habitat enhancement are minimized as natural controls and limits apply once production increases to the point that habitat capacity is reached – or when the enhancement activity is halted.

In short, interactions between pre-existing salmon and those resulting from habitat enhancement are of limited concern. Habitat enhancement activities may be of widely varying effectiveness; the most successful, large projects will have a significant impact on wild salmon production. Ecological changes may occur, and fishery management issues may increase, but impacts should, on the whole, be beneficial to wild salmon.

10.1.2 Key interactions with wild salmon related to channels and ponds (artificial habitat with natural spawning and rearing)

Increasing the rate of survival through the use of artificial channels for spawning and rearing increases potential negative interactions with wild salmon, as compared to the methods discussed above.

The potential impacts of providing artificial habitat are project-specific. They are primarily related to the relative scale and rate of enhancement at both the enhancement project level and in the area of the fisheries within which the enhanced population is harvested. Projects with significantly higher survival rates than the natural stocks they interact with or are harvested with could have significant adverse interactions. Relatively small enhancements, and those with near natural survival rates, likely have very limited interactions of concern to wild salmon.

Possible positive interactions include increased spawners in natural habitat and increased nutrients and productivity in streams and lakes from increased carcasses. Monitoring and assessment at channels provides increased information on local stocks, their productivity, behaviour, survival rates and other factors important for habitat and fisheries management. Thus, while channels add to complexity of assessment and management, they generally provide important assessment information that would otherwise not be available.

The main means of mitigating the negative impacts of spawning and rearing channels is fisheries management that strives to reduce over-harvesting of wild stocks mixed in with enhanced stocks (e.g. establishing sustainable harvest rates).

Mixed stock fisheries interactions: If the enhanced fish are harvested with wild fish there can be mixed stock fisheries impacts on the wild fish. The level of impact is related to the survival rate and number of enhanced fish relative to wild populations in the fisheries within which the enhanced population is harvested. Unless harvesting is population selective, if there are large numbers of enhancement returns, unenhanced populations could be over-harvested and/or the enhanced populations under-harvested. Under-harvest/over-escapement of enhanced populations might increase straying and might result in health problems.

The relatively small size of some individual projects might suggest that they would result in minimal mixed stock fisheries problems. However, this production must be considered in the context of the overall enhanced production and production rates in the fisheries within which the enhanced population is harvested. As these habitat improvements provide lower survival rates than hatcheries they should be less problematic than hatcheries. The larger chum and sockeye facilities require special fisheries management actions to avoid mixed stock fisheries impacts on wild stocks. Fisheries should not be managed so as to respond only to hatchery fish abundance.

Genetic interactions: Because salmon home to the areas in which they were incubated, it is possible that genetic selection resulting from the artificial habitat accumulates in the enhanced fish. There should be limited unnatural genetic selection as long as fish are free to use facilities without intervention. If there is consistent timing or other selection of fish permitted to access spawning channels, the risk of genetic impacts increases. Genetic impacts apply to spawning channels more than to rearing channels.

Competition: If composite enhanced production is large for the system it could result in competition for freshwater, estuarine or early marine food/space within and between species. This is most likely for coho that rear extensively in these areas. Sockeye rear in lakes and therefore compete with wild sockeye but less with other species than do salmon rearing in streams. However, large abundances of sockeye in the ocean can result in decreased average size of adults. Pinks size may also be affected by abundance in the ocean.

Predation: Increased production of some species, such as coho, might result in increased predation on pinks. Increased production will likely attract an array of predators, especially if the increased production is consistent between years. Predation impacts are highly dependent on the characteristics of the natural system.

Health: Excessive spawner density in channels tends to increase the chance of the spread of disease, especially under adverse conditions, such as warm water. However, this same phenomenon applies in natural rivers.

Habitat impacts: Large channels could affect surface and ground water use, depending on water sources. Large channels could also affect nutrient load from carcasses and dead eggs in the stream. For large channels, water temperature in the river could be increased in the summer, unless the channel is temperature controlled. Increased nutrients and temperature could promote biotic change in the stream. Lake and stream enrichment from this process, in the extreme, could have impacts similar to those discussed in relation to lake and stream enrichment above. Depending on the site design, impacts can be isolated.

10.1.3 Key interactions with wild salmon related to hatcheries (human controlled spawning and rearing)

Hatcheries, which involve human control of spawning, incubation and rearing, have the highest potential for causing negative interactions with wild salmon. However, the question of magnitude is critical in the assessment of risks from hatcheries. For example, genetic changes to hatchery fish may be inevitable, but how extensive these changes will be and how strongly they will affect wild salmon is an open question.

Enhancement can be used to rebuild at-risk populations. When a population/stock gets to a very low level there are few options for rebuilding it other than some form of enhancement. The lower the abundance of the stock is (the more at risk it is), the more security of production and the lower the risk of a failure of enhancement is required. This leads to the challenging situation in which the most at-risk stocks are the most in need of enhancement, yet the least able to absorb failed enhancement attempts, or negative impacts of those attempts.

Regulations, guidelines and protocols, and improved hatchery technology, if implemented, can reduce the impacts of hatcheries on wild salmon, but cannot eliminate the risks.

Mixed stock fisheries: The generally large production and high survival rates related to hatchery releases are more likely to cause mixed stock fisheries problems than most other forms of enhancement. The large numbers of salmon produced by hatcheries can support much higher harvest rates than wild stocks can sustain. This may be the most serious problem resulting from enhancement in B.C. , with the worst impacts relating to Georgia Basin hatcheries. Fishery management provisions and improvements in selective harvesting techniques are being developed to lessen mixed stock harvesting risks to wild salmon.

Genetic: In a hatchery most of the freshwater life stage is controlled, including selection of spawners and incubation selection, so there is an opportunity for genetic selection for domestication (i.e., selection for fish that can best survive in the enhancement environment). Genetic concerns relate to selection of spawners, matings, limited number of parents, domestication of enhancement production, inbreeding, and other potential problems. Creation of hatchery stocks could result in fish that have lower survival or reproductive success in the wild, due to the loss of genetic traits important for survival in the natural environment. Interbreeding of these fish with wild fish can degrade the genetic fitness of the wild fish. This is worst where a hatchery-specific stock mixes with wild stocks through straying. Various procedures, if followed closely at the hatchery (e.g. in the selection of broodstock), can reduce genetic risks to wild salmon but not eliminate them (Waples 1999).

Ecological interactions (competition and predation): The high levels of production from hatcheries can affect competition and predation in the watershed, estuary and coastal areas. Hatchery fish may prey on wild fish, but the more prevalent negative interaction is the attraction of predators such as birds and seals, which prey on both wild and hatchery salmon. Competition may be a serious problem when hatchery and wild fish compete for limited supplies of food in freshwater or marine environments. During adverse climatic phases, or ocean regimes, in which marine food supply is limited, the inferred impacts of competition are worsened. Measures to reduce ecological interaction involve decisions about the location, quantity, size and timing of hatchery releases to minimize conflict with wild stocks.

Fish Health: High-density incubation and extended high density rearing can promote the spread of disease within a hatchery, and hatchery fish could then spread disease to wild fish in the watershed. As well, effluent from the hatchery could spread disease into the natural environment if it is contaminated with pathogens (and not sufficiently treated to remove the contaminants).

Habitat Impacts: Hatcheries and their surrounding infrastructure can have immediate impacts on the riparian habitat where they are located. Ongoing habitat impact concerns are primarily related to water use. Hatcheries can release nutrient enriched, cold or warmed water that might positively or negatively impact naturally incubating or rearing fish in the stream receiving the hatchery outflow.

10.2 Overview of estimated impacts of enhancement on wild salmon

The review of knowledge gaps in Section 9 indicates that definitive, quantified assertions of enhancement impacts on wild salmon would be unjustified. Yet what little we *do* know about interactions between enhancement and wild salmon provides more than sufficient grounds to suggest that some enhancement activities are among the factors that are putting wild salmon stocks at risk. The key questions are questions of degree: Where are the areas of interaction and what are the related types of enhancement of serious concern? Which ones are relatively low risk? What are the central factors that increase or reduce the risk?

> *"It is easy to identify risks that hatcheries pose for natural populations; it is not so easy to predict whether deleterious effects will occur in any given situation, or, if they do, how serious the consequences will be." (Waples 1999 p.13)*

Assessment of the various risks to wild salmon from enhancement needs to take into account:

- what we predict about potential interactions in theory, based on fundamental understanding of salmon biology, ecology, and enhancement activities;
- what we know about actual interactions, from research and experience;
- the availability and potential effectiveness of measures that can mitigate negative impacts;
- the supporting institutional arrangements for the implementation of mitigation (legislation, policy, guidelines); and
- the gaps in our knowledge base.

These are the puzzle pieces that this report has assembled. Putting them together, we make estimates of the level of risk posed to wild salmon and summarize the key factors involved (in the next section). Section 10.2.2 acknowledges the benefits to wild salmon from enhancement, and Section 10.2.3 places enhancement in a broader context in terms of time, space and diversity of impacts on wild salmon.

10.2.1 Summary of risks to wild salmon from enhancement and the key factors involved

The key factors that determine the risks posed to wild salmon from the various types of enhancement are:

- *scale of production,*
- *relative production,*
- *level of intervention (method of enhancement),*
- *species of wild salmon involved,*

- *enhancement strategies and practices (purpose of the hatchery, type of hatchery – segregated or integrated, operational guidelines, how well the guidelines are implemented)*
- *types of interactions, and*
- *level of understanding.*

The scale of enhancement activity is an important determinant of risk. To some extent, the larger the enhancement activity in terms of the numbers of enhanced fish it adds to the ecosystem, the higher the chance that it will have an impact: *scale of production* tends to act as a multiplier on some of the risk factors. For example, enhancement projects producing large numbers of salmon are more likely to lead to competition for habitat with wild salmon.

Figures 8 to 10 present a qualitative interpretation of relative risk of various types of interactions, relative to levels that occur naturally, by enhancement method (Figure 8 and 9) and for each enhanced species (Figure 10). These ratings are generalized over the broad geographic stock and project range of experience beyond published information. For Figures 8 and 9, 'None' means no difference from natural. 'Unlikely' is very low chance that that there will be a larger interaction than occurs naturally. 'Possible' indicates that under some conditions interactions will exceed natural levels. 'Likely' signifies that in most cases interactions will be significantly higher than natural. For Figure 10, 'Unknown' means couldn't find any experience of species interaction. 'Low' indicates a very low chance of exceeding natural interacvtions, given the major types of enhancement used in B.C. 'Moderate' signifies about a 50% chance of some level of adverse interaction. 'Low-Mod' is about half way between moderate and low. 'High' means that there is almost certainly some level of adverse interaction that exceeds natural levels. 'Mod-High' is about halfway between high and moderate.

Table 8, focusing on large enhancements, estimates higher expected impacts than Table 9, which looks at small enhancements. Composite levels of enhancement from a number of projects in the same area affect wild salmon as much as a single large project.

Table 8: Relative average risk of various types of interactions by enhancement method for large enhancements.

For example, as salmon from large channels often have higher average survival rates than salmon from obstruction removal or habitat restoration, channel production is more likely to be able to sustain higher harvest rates. Consequently, large channels are more likely to result in increased mixed stock fishery over-harvest of wild stocks. Also, the high production from large channels increases the likelihood of competition with wild stocks. Other possible interactions associated with large channels are considered possible but less likely. The darker the box is the more the potential impact, from none to likely. Methods of enhancement are listed in increasing level of intervention from left to right.

INTERACTIONS	Obstruction	Habitat	Lake/Stream	Channels	Controlled	Controlled	Hatcheries
	Removal	Restoration	Enrichment		Spawning	Rearing	
MIXED FISHERIES	unlikely	none	possible	likely	likely	likely	likely
GENETIC	unlikely	none	unlikely	possible	likely	likely	likely
COMPETITION	none	possible	possible	likely	likely	likely	likely
PREDATION	unlikely	possible	possible	possible	possible	possible	possible
FISH HEALTH	none	none	unlikely	possible	possible	possible	possible
HAB. DEGRADATION	none	none	none	possible	possible	possible	possible

Table 9: Relative average risk of various types of interactions by enhancement method for small enhancements.

For example, as salmon releases from small hatcheries are often a small percent of total juvenile salmon in a river, the potential impacts are lower than for large hatcheries. However, if small hatchery releases account for a large percent of total juveniles, the impacts are likely to be similar to those of large hatcheries. The darker the box is the more the potential impact, from none to likely. Methods of enhancement are listed in increasing level of intervention from left to right.

INTERACTIONS	Obstruction Removal	Habitat Restoration	Lake/Stream Enrichment	Channels	Controlled Spawning	Controlled Rearing	Hatcheries
MIXED FISHERIES	none	none	unlikely	unlikely	unlikely	unlikely	possible
GENETIC	unlikely	none	unlikely	unlikely	possible	unlikely	likely
COMPETITION	none	unlikely	possible	possible	possible	possible	possible
PREDATION	unlikely	unlikely	possible	possible	unlikely	possible	possible
FISH HEALTH	none	none	unlikely	unlikely	possible	possible	possible
HAB. DEGRADATION	none	none	none	unlikely	unlikely	unlikely	unlikely

In both cases (large and small enhancements), the potential impacts and concerns generally increase as the *level of intervention* increases. Obstruction removal and habitat restoration pose only some "possible" risks while the risks from the more intensive enhancements range from "possible" to "likely." A key reason that the higher intervention methods pose higher risks is that as the duration of time spent under enhancement influence increases, the risk of genetic impacts increases. Fish incubated and reared in a hatchery are subject to selection pressures for a longer period than those using channels. Health risks also increase with the duration of time spent in a facility.

The risks from the different types of interaction vary significantly according to the *species of wild salmon involved*. These interaction risks are shown in Table 10. Generally, it is the hatchery-enhanced species that have the highest potential for adverse interactions. Some specific differences in risks to various species are:

- Chinook, coho, steelhead and cutthroat are mainly produced in hatcheries where they are subject to genetic and other selective pressures during the period they are reared in the hatchery. Also, if these species are released before they are smolts, they will compete with resident wild fish in the freshwater rearing stage and could affect wild survival rates.

- Because pink and chum salmon do not spend a significant amount of time rearing in fresh water, in the hatchery they have a lower risk of competition, predation, genetic and fish health interactions. Pink releases are limited and generally do not result in significant mixed stock fishery impacts. Chum releases are much larger, but most are harvested in terminal fisheries that target enhanced stocks so have minimal mixed stock fisheries impacts.

- Chinook and coho are fished in coastal fisheries throughout most of their marine life and so are subject to sequential and mixed stock fisheries. Large production of hatchery chinook and coho with high survival rates relative to natural rates, contributes to harvest rates that are too high for wild fish to sustain. Also, coho are known to prey on juvenile pinks, so enhancement of coho can pose a risk to pink salmon.

- Sockeye are likely at highest risk from disease transfer, due to their susceptibility to IHN disease. To manage this risk there are specific protocols for controlling and preventing the spread of IHN. Fisheries on enhanced sockeye are also specifically managed to minimize adverse mixed stock fisheries impacts on wild stock risks.

Table 10: Relative level of concern regarding interactions for each species.

For example, for sockeye enhancements the biggest concerns are mixed stock fisheries and fish health. The mixed stock fishery concerns are related to high survival rates from large spawning channel production. Also, as sockeye are generally more susceptible to Infectious Hematopoetic Necrosis (IHN) disease than other species, the health risks in hatcheries are higher than for other species. The darker the box is, the more the potential interaction and concern.

IMPACTS	Chinook	Chum	Coho	Pink	Sockeye	Steelhead	Cutthroat
MIXED FISHERIES	High	Low-Mod.	High	Low-Mod.	Mod-High	Low	Low
GENETIC	High	Low	High	Low	Low	High	High
COMPETITION	High	Low	High	Low	Low	High	High
PREDATION	Moderate	None	High	None	None	Unknown	Unknown
FISH HEALTH	Low	Low	Low	Low	Mod-High	Low	Low
HAB. DEGRADATION	Moderate	Low	Moderate	Low	Moderate	Moderate	Moderate

While hatcheries are clearly the method of enhancement that poses the highest level of risk, the actual risk posed by a hatchery depends on *enhancement strategies and practices*, in addition to size and relative production. The *purpose of the hatchery* makes a difference – whether production or conservation. Hatcheries are increasingly conservation oriented, with attendant lower risks. The *type of hatchery* is also important – whether segregated or integrated. B.C. hatcheries are mainly of the integrated type, which strives to minimize the differences between the enhanced fish and the wild fish with which they interact. For example, if effective, integration reduces negative genetic interactions. Another important factor is *operational guidelines*, which, if carefully followed, can reduce risks significantly. For example, the timing of releases from the hatchery affects mixed stock fishery interactions; the size of the fish released influences competition and predation interactions; and the conditions in the hatchery affect fish health, influencing the risk of disease transfer to wild fish. Advances towards improved guidelines have been made in the U.S. and in B.C. over recent years; it is not clear, however, *how well the guidelines are implemented* in each enhancement project.

The *interactions* listed in the preceding tables are shown in order of the severity of the risk they pose to wild salmon. *Mixed stock fisheries* is at the top of the list because research has identified situations where wild salmon have been negatively impacted at a large scale, with the worst impacts relating to Georgia Basin hatcheries. Fishery management provisions and improvements in selective harvesting techniques are being developed to lessen mixed stock harvesting risks to wild salmon.

Genetic interactions are listed as the second most serious interaction. Although evidence for actual impacts is scarce, theory indicates that enhancement could significantly reduce the genetic diversity and fitness of wild salmon. Genetic changes to hatchery fish may well be inevitable; the uncertainty relates to how extensive these changes are and how strongly they affect wild salmon. Hatchery practices implemented in recent years have considerably alleviated the risk of genetic impacts but the risks are still significant.

Competition, predation and health interactions are particularly poorly understood. *Competition* is listed as the third most serious risk because a few studies have pointed to negative impacts on wild salmon, and due to increasing concerns about limited carrying capacity not only in freshwater habitats but at sea as well.

Predation interactions are a clear risk in theory, and they have been shown to have a negative impact on wild salmon in some cases. Yet other studies have shown that the presence of enhanced salmon can have a neutral or even positive effect on predation on wild salmon.

No studies illustrating negative *health interactions* between enhanced and wild salmon could be found through this research. Nevertheless, the potential for disease transfer from enhanced to wild fish does exist, since conditions in hatcheries can lead to disease, which in theory can then be transferred to wild fish through water or fish-to-fish.

Negative impacts of enhancement facilities on local *fish habitat* are possible but research has not identified these as significant. They are the most localized and the easiest of the potential interactions to mitigate or avoid.

While the *level of understanding* of ecological interactions was highlighted above as being inadequate, there is a serious shortage of information regarding all the forms of interaction between enhancement and wild salmon explored in this report. This does not provide room for complacency. Quite the reverse: in terms of the precautionary approach, the level of uncertainty regarding potential impacts of enhancement on wild salmon is so high that we should reconsider the current scale of enhancement activities in B.C., particularly in the form of hatcheries.

10.2.2 Benefits of enhancement to wild salmon

The aim of this report was not to do a cost-benefit analysis of enhancement. The focus of the analysis instead has been on possible negative interactions between enhancement and wild salmon. However, various sections of the report do identify benefits of enhancement to wild salmon (in italics below), and certain general statements can be made.

Benefits from lower-intervention enhancement methods are accompanied by few risks to existing salmon populations. These methods include obstruction removal, improved or restored natural habitat and lake and stream enrichment. *The benefits of these activities were summarized in Sections 6.1, 6.2 and 6.3.* The effectiveness of these means of enhancement in producing salmon may vary widely, but their impacts on wild salmon are generally likely to be positive if they are effective at all.

Effective enhancement at higher levels of intervention – major spawning channels and hatcheries – provides benefits to the extent that the enhanced fish increase the number of spawners. *Section 5.1 discusses the contribution of enhancement to production,* including the potential for enhancement to increase the natural productivity of wild fish.

Enhancement programs also provide indirect benefits to wild salmon. The presence of enhancement facilities, community participation, and school programs associated with enhancement can raise public awareness of the importance of salmon and the need to protect them. Hatchery staff and facilities contribute to other community, habitat, and fisheries management activities, which can in turn improve the production of wild salmon. These secondary benefits of enhancement to wild salmon are not explored in this research.

Another indirect benefit of enhancement to wild salmon is the information generated through monitoring and assessment in conjunction with enhancement activities. This information can improve the effectiveness of enhancement and contribute valuable data to improve fisheries management and conservation. *This function of SEP is discussed in Section 8.1,* which provides a broader discussion of the assessment of enhancement effects.

10.2.3 Putting enhancement into a broader and long-term context

Enhancement is only one of a number of factors that affect the abundance of salmon. These factors vary somewhat independently of each other and often differentially impact species as well as populations. Some of the factors can affect both wild and enhanced populations; others only affect wild fish. To assess the impacts of enhancement it is essential to also monitor these other factors so that there is an overall awareness of all of the changes taking place that are affecting the salmon. Appendix 4 provides more detail on the factors that have impacted salmon abundance over the last 100 or so years.

In the last 100 years, people have caused the biggest changes, including intensive harvesting, freshwater habitat damage and enhancement. Other changes include climate change (some of which is human-caused) and cyclic changes in ocean productivity.

Sockeye production has been most affected by habitat damage, primarily by the Hells Gate and Babine slides. Conversely, sockeye production has been positively affected by providing upstream access by constructing fishways and removing obstructions.

In contrast, the dominant impact on chinook and coho abundance seems to have been over-harvesting, including problems stemming from mixed stock fisheries. The long-term declines in catch have been apparent and consistent since the 1920s for chinook and 1940s for coho. Since the 1960s, first U.S. and then Canadian enhancement has aggravated these mixed stock fisheries. The impacts of ocean productivity cycles may have also significantly impacted both chinook and coho production.

Over-fishing has decreased the number of chum salmon populations contributing to production. Abundance may also have varied with ocean productivity cycles. Chum salmon have also been significantly impacted by loss of accessible spawning habitat, particularly in the developed area around the Georgia Basin. Since the 1970s, enhancement and habitat restoration, in conjunction with improved harvest management, have resulted in rebuilding of populations and production.

Different mixes of these factors in different areas have affected pink salmon production. Fisheries likely have had the dominant impact. Of particular concern is that fewer populations are contributing to production (PFRCC 2002 p. 39, 68).

Little is known about steelhead production or how it has been affected by these various factors.

In the last few years we have learned that ocean productivity can dramatically affect salmon survivals and production. Almost all Canadian enhancement has occurred within a single low productivity ocean regime. The little information that is available from the previous regime indicates much higher survivals for both enhanced and wild fish, and we may now be entering a regime of improved productivity again. However, we cannot yet predict survival well or early enough to adjust overall management of fisheries and enhancement. Furthermore, in rearing areas in the high seas enhanced and wild salmon from Japan, Russia and the U.S. all compete for food – so effective responses would require international coordination of fisheries management (especially mixed-stock fisheries) and, ideally, enhancement efforts.

Loss of freshwater habitat capacity is continuing, in some areas much faster than habitat restoration and enhancement. The number of populations contributing to salmon production is still decreasing, as is the information on the abundance and status of those populations.

At this overview level the main enhancement success stories are improved access to freshwater habitat for sockeye, and coordinated chum enhancement and management. The main failure is coho enhancement in the Georgia Strait, not because the enhancement did not produce fish but because other factors were not taken into account. In particular, the mixed stock fishery was not controlled and the number of populations and their level of production were not monitored and managed for.

In short, without more continuing information on the various factors affecting salmon production, it is difficult to separate the impacts of enhancement on wild fish from these other factors. Yet the importance of taking into account other environmental factors and human activities affecting the status of wild salmon cannot be over-stated. As explained by Meffe in a 1992 article:

> *"a management strategy that has as a centerpiece artificial propagation and restocking of a species that has declined as the result of environmental degradation and overexploitation, without correcting the causes for decline, is not facing biological reality. ... [Worse, hatchery production can conceal from the public] the real problems and dangers facing a valued resource." (p. 351-352)*

10.3 Guiding principles

Based on the foregoing analysis, we have generated the following seven guiding principles. Together, they present an approach for pursuing enhancement objectives while at the same time minimizing impacts on wild salmon. As the previous sections of the report demonstrate, much is known about the effects and impacts of enhancement facilities – yet our understanding is only partial in many cases, and we will never have complete knowledge. These principles stress the need to act on the knowledge that we have, while steadily building that knowledge over time, so that solutions can be continually adapted to respond to changing conditions.

We hope that better-informed decision-makers, user groups, community representatives and individual citizens who understand the risks that enhancement poses to wild salmon will consider and observe these guiding principles in structuring and operating future enhancement programs.

10.3.1 Operate hatcheries and enhancement facilities with primary regard for their potential impacts on wild salmon.

As a general principle, hatcheries and enhancement facilities should be operated with a conservation emphasis – with primary regard for their potential impacts on wild salmon. Given that conservation of wild salmon stocks is a primary priority, hatchery management and operation should increasingly be driven by biological concerns. This means conducting all enhancement activities to the highest standards of practice that will minimize risks to wild salmon – "with regard for the biological restraints of the populations involved." (Brannon 1993 p.25)

The concept of a "conservation hatchery" – a hatchery that emphasizes conservation over production objectives – is relatively new. Flagg, Iwamoto and Mahnken assessed the status of conservation hatcheries in the U.S. Pacific Northwest and provided a template of protocols that they recommended for adoption to fully test the conservation approach in a given hatchery. They concluded that, as of 2001, "various production hatcheries are applying some individual conservation strategies" and that "these strategies are (1) not being uniformly applied; (2) not covering the full spectrum of potential strategies, and (3) only in select cases receiving adequate monitoring and evaluation." (Flagg et al. 2002)

Others have observed that there is little excuse for lack of attention to the impacts of hatcheries on wild salmon, or for failure to implement measures that will reduce those impacts: "Now that we have better information and better science, they [hatcheries] should be used much more carefully than they were 20 and 30 years ago." (Fraser in Government of Canada 2003a) And where negative impacts are ongoing despite best efforts to mitigate them, closure of the facilities in question should be considered. Along these lines, it was suggested at a recent Vancouver symposium that consideration be given to the creation of "enhancement-free zones" to provide areas where salmon could be fully protected from the risks of enhancement (Routledge 2002). If, however, such zones were to significantly benefit wild salmon, they would also have to be free of other adverse impacts.

Enhancement technology has generally been used to achieve objectives that society believes are worthy ones. In the past, that may have meant primarily production for economic or recreational benefit. However, in recent years a stronger emphasis on conservation has emerged and become embedded in legislation like the Species at Risk Act and international treaty obligations that call for observance of the precautionary principle in resource management decisions.

The appropriateness of enhancement activities that pose risks to wild salmon, and the tolerance for such risks, reflect this balancing between production and conservation goals. When the higher priorities were cost recovery from enhancement projects, or the maintenance and improvement of fishing opportunities, risks to wild salmon might have been considered worth taking. The higher a priority placed on integrity of wild salmon populations, the less tolerance there should be for the risks enhancement poses to wild salmon.

The level of success of enhancement programs in the pursuit of their goals also affects the way we look at risks to wild salmon. The more successful a program is in reaching goals related to production for harvest, the more threat it may pose to wild salmon through sheer numbers. However, if enhancement is failing,then even low risks to wild salmon may be deemed not worth taking. If enhancement promises benefits to wild salmon, such as alleviating the demographic and genetic risks of severely depleted populations, these benefits may outweigh the risks.

10.3.2 Treat enhancement projects like experiments; learn from the results; and change practices to minimize impacts on wild salmon based on the lessons learned.

Every enhancement project should be treated like an experiment. The processes that create negative interactions with wild salmon are multifaceted. Since there is wide variability of circumstances from one enhancement setting to the next, "one size fits all" solutions are not appropriate. Rigorous experimental design, clear objectives, and monitoring and assessment protocols should be tailored specifically to each facility and setting. If and when the results of enhancement projects point to the need for changes in approaches to enhancement, those changes should be made and the next experiment begun.

Many of the studies needed to fill the gaps in our knowledge of the impacts of enhancement on wild salmon are complex, long-term and expensive. While efforts are made to initiate and fund these studies, actions to minimize risks based on what we have learned should be taken now. This point is discussed further with reference to the last guiding principle, in Section 10.3.7.

10.3.3 Undertake research, monitoring and assessment to provide a solid foundation for evaluation of enhancement and adaptive management.

This report has demonstrated the complexity of interactions between wild and enhanced stocks. Research programs associated with enhancement facilities should therefore monitor not just short-term, local impacts, but also the broader context in which enhanced and wild stocks co-exist and in which they are assessed. Many variables affect the health of wild and enhanced salmon populations, including fisheries; habitat degradation and climatic effects in freshwater; ocean productivity and regime shifts; enhancement activities and scale of production. Each of these variables must be monitored in both the short and long term, so that we may know which factors are causing what effects on salmon. Long-term monitoring and assessment makes it possible to observe cyclic and other long-term effects. Without such information it is not possible to be sure of the actual impacts or results of enhancement. It is also not possible to know if an observed change is a result of enhancement interacting with changes in one or more of these other factors.

It is critical to the improvement of the effectiveness of enhancement, and to the minimization of risks to wild salmon, that decision-making about hatchery programming and operations be scientifically defensible, responsive and well-informed (NPCC 2003). In addition to improved monitoring and assessment, much more research is required on fundamental topics such as genetic interactions and the role of ocean regime changes. Large scale, long-term experiments may be required. Until the situation improves, much caution should apply.

To help focus the research agenda, we have identified some critical information needs in various areas. Regarding *mixed-stock fishing*, current assessment capabilities should be maintained and expanded, and a core program of research and analysis should be designed. In the area of *genetics*, priority should be given to development of appropriate management guidelines that apply the latest scientific findings. Regarding *ecological interactions*, there is a need for further research on the management of large hatcheries in periods of varying ocean productivity. There may also be a need to design large scale, long-term research programs that would be able to test definitively for interactions. Finally, in the *health* area, continuing surveillance seems to be called for, even though health issues do not appear to be pressing at the present time.

The recent hatchery reviews in Washington State, in the Columbia Basin, and by the U.S. federal agency NOAA, have provided current and comprehensive frameworks for data analysis. Canadian scientists have participated actively in these efforts. Many of these operating and performance guidelines should be fully considered in Canada. When initial results of the Washington hatchery reform program were presented at the SFU hatcheries conference in 2001 (Orr and Penikett 2002), there was discussion about conducting a similar review in B.C., but this has not happened.

Funding should be applied to a careful review of SEP facilities: "Each hatchery should be rigorously evaluated according to the extent to which it contributes to the conservation of naturally spawning salmon populations." (Glavin 2003 p.55) Such reviews and evaluations should be directed at finding out what we need to know in order to decide whether facilities should be scaled back, closed, or possibly expanded to support the conservation of wild salmon.

10.3.4 Use a combination of enhancement and management strategies to protect wild salmon, focusing on the early implementation of less interventionist approaches.

Hatcheries are not, by themselves, the answer to diminishing wild salmon; rather the solution is to use a mix of measures. Measures to protect and rebuild wild salmon should involve a combination of: habitat protection and restoration; some expansion of habitat through obstruction removal, artificial habitat and lake and stream fertilization; changes to fishing practices such as improved selective harvesting; constraints on harvesting levels; and the controlled use of hatcheries. Given that salmon cultivation techniques have not been proven as a conservation technology and that there are risks posed to wild salmon by larger scale enhancement projects (hatcheries and artificial spawning channels), care should be taken to mitigate their risks and to use them only in circumstances where the risk is judged to be acceptable. Furthermore, a focus on large-scale, high intervention enhancement activities places the focus on mitigating the declines in salmon populations (i.e., the symptom of a problem) rather than addressing the actual causes of the declines – essentially a palliative approach (Meffe 1992).

Ideally, the lowest-intervention forms of enhancement should be used early, before stocks have dramatically declined, and before there is a pressing need for large-scale, high intervention enhancement. In the Columbia Basin setting, the NPCC has recognized that it is most effective to link enhancement strategies to the conditions of habitat, the potential of habitat for restoration, and the biological potential of the target species (NPCC 2003).

NPCC's concept of a continuum of intervention related to the degree of habitat degradation can and should be adapted to the B.C. context. The stages in this continuum, shown below, are not meant to be comprehensive or definitive. They are presented only to illustrate the logic of taking more interventionist enhancement measures after lower intervention enhancement and fishery management measures have been attempted.

- Intact habitat, healthy wild stocks – protect the habitat and use no enhancement.
- Intact habitat, declining wild stocks – protect the habitat; reduce harvesting pressure; use no enhancement.
- Restorable habitat, declining wild stocks – use appropriate enhancement methods to restore the habitat; reduce harvesting pressure; try lake and/or stream enrichment and, if necessary; use channels and hatcheries for interim or limited supplementation.
- Restorable habitat, threatened stocks – use appropriate enhancement methods to restore the habitat; close fisheries; use limited or full supplementation via channels and hatcheries.
- Eliminated habitat – use replacement hatchery.

Appendix 5 provides two examples of integrated approaches to enhancement that have been employed in B.C.: the Clockwork management program (Stave River case) and the restoration of Rivers/Smith Inlet.

10.3.5 Counteract the tendency to shift baselines toward acceptance of higher levels of conservation risk.

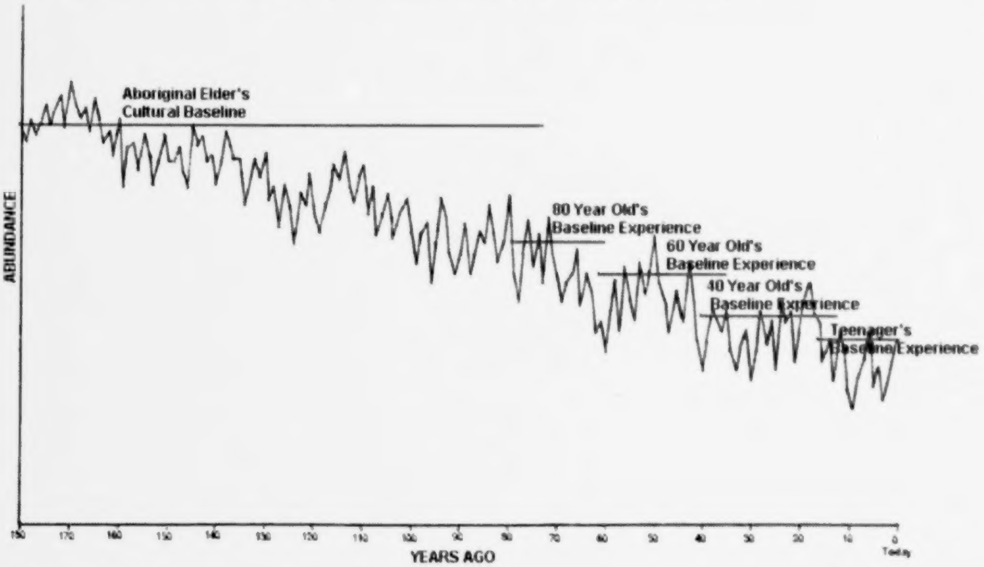
Comprehensive monitoring and assessment programs can help to avoid the otherwise normal tendency to accept a slowly changing definition of the "normal" condition of a stock. Peoples' perception of the state of fisheries resources is coloured by their experience. A young person with few years of experience sees current conditions as normal. Her 80-year-old grandparents view the same conditions as a drastic decrease from conditions that may have prevailed earlier in their lifetimes. Cultural experience can also affect perception, as in the case of First Nations culture which retains memory of earlier salmon abundance in cultural records, traditions and the recollections of elders.

Most management actions taken in habitat conservation, enhancement and fisheries management make assumptions based on current perceptions of what is acceptable. These perceptions provide a "baseline" against which changing conditions and events are evaluated. Perceptions are in turn based in experience. The more recent a person's experience of the natural environment, the more normal a highly altered environment will seem to them. Thus, standards of acceptability regarding what is "intact" or "healthy" regarding habitat, or what are acceptable levels of production or escapement with regard to harvesting pressure, have a tendency to decline over time. This tendency has been termed the "shifting baseline syndrome" (Pauley 1995).

Figure 24 illustrates the syndrome. The declining trend line in the figure might be a salmon population that has decreased by more than 50% over a 150-180 year period. The figure shows how the young person's view of a good or acceptable salmon abundance differs significantly from that of their parents or grandparents. In aboriginal populations with a long history of fishing, the cultural experience of the elders may be significantly different from the elders' personal experience.

Figure 24: Shifting baseline syndrome.

Decreasing stock abundance is superimposed with various age groups of peoples' experience.



If the figure were illustrating development impacts on salmon habitat, the trend line would be low in the early period and steadily increasing to the present. Rapid change, as for example the development on Vancouver Island from Nanaimo to Campbell River, is visible and people react to it. Slower development is often not noticed as being significant. However, over 100 years even slow change can be very significant.

Decreasing expectations lead to acceptance of declining baselines and to the foregoing of resource potential. This process also carries the resource toward conservation risk levels and toward extinction without any real perception of change. Accordingly, in the interest of wild salmon conservation, the natural direction of the trend in "shifting baselines" needs to be reversed. Our assessment of current conditions needs to be informed by the long-term context.

10.3.6 Ensure that the goals of enhancement are clearly stated.

Enhancement can only contribute effectively to the achievement of agreed-upon objectives if the goals for the affected stocks are clearly articulated. An example of careful analysis that led to the setting of appropriate enhancement objectives was the planning process of the Coho Steering Committee (Coho Steering Committee 1992). One of its recommendations was to use enhancement to augment declining stocks in cases where regulatory measures would be inadequate to prevent the exploitation of certain stocks at levels higher than the target level. This would apply only to "a few stocks that need additional assistance." (p.29) The committee also recommended that "Enhancement should not be increased solely to maintain current catch levels during the wild stock rebuilding period." (p.30)

Clear statements of enhancement goals will become increasingly important in directing the activities of hatcheries that seek to balance production and conservation. They will be critical components of enhancement programs that combine multiple types of low-intervention strategies.

10.3.7 Act on what we do know.

Even though there are gaps and uncertainties in our understanding of the impacts of hatcheries and enhancement strategies on wild salmon, there is much that we do know. We can and should act on the knowledge that we have, without waiting for final certainties and definitive research results – which, by the nature of the subject matter, are not likely to be forthcoming.

Scientists have acknowledged the weaknesses of American and Canadian hatchery and enhancement systems for decades. In the U.S. this appears to have had little effect on operations or operator culture. Only in recent years has the threat of legal action under the Endangered Species Act brought about the beginnings of meaningful change. It remains to be seen whether the newly-enacted Species at Risk Act will bring about similar change, focusing of attention, and increased seriousness in the Canadian setting (Boyd 2003).

Yet the pressure of new legislation should not be necessary in order to launch new initiatives to minimize negative interactions between enhancement and wild salmon. As soon as possible, a review of B.C.'s existing hatcheries and enhancement facilities should be undertaken, identifying those that may pose the most hazards to the wild salmon. Actions should be taken to make their operations more "wild salmon-friendly." In Section 8.2 of this report mitigative measures and improvements that could be implemented in individual cases are listed (many of which are already used in varying degrees).

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GLOSSARY

A useful source of definitions of terms related to salmon, fisheries and enhancement is the Dictionary of Ichtyology: http://www.purethrottle.com/briancoad/Dictionary/A.htm

Adaptability:	The capability of an organism to adapt to changing or future environmental conditions, the capability depends on adequate genetic variation remaining in the population.
Adaptation:	A genetically determined trait that increases the relative fitness of an individual in its environment (an adaptation refers to a current trait and results from the integration of past genetic and environmental interactions).
Adipose fin:	A small fleshy fin lacking rays or spines, posterior to the soft dorsal fins.
Age-class:	The brood year (year the fish was born) or the salt-water entry year that defines a cohort of fish (same as year class).
At risk stocks:	Weak stocks, which are at risk of becoming endangered (legal terminology, SARA), or stocks that have been identified as being in need of rescue or in need of specific management practices because of low or declining populations.
Broodstock:	The pool of captured adult salmon a hatchery has available for artificial spawning. This pool can be made up of wild and/or returning hatchery salmon.
Captive broodstock program:	Collection of individuals (or gametes) from a natural population and the rearing of these individuals to maturity in captivity.
Carrying capacity:	A measure of the amount of a population that can be supported by a particular ecosystem. Carrying capacity changes over time with the abundance of predators and resources like food and habitat.
Clockwork Management:	"Formula" or "Clockwork" management lays out management options by time period for different stock abundances, timing and mixes, fleet sizes and mixes and environmental conditions in relation to key indicators so that in-season management can proceed like "clockwork" through the plan which was agreed to pre-season.
Coded wire tags:	Also known as CWT. Microscopic wire etched with an identification code. Tags are inserted into the nose cartilage of salmon to identify them.
Density dependence:	The dependence of a factor influencing population dynamics (such as survival rate or reproductive success) on population density. The effect is usually in the direction that contributes to the regulative capacity of a stock.
Depensatory:	Mortality is depensatory when its rate (i.e. the proportion of population affected) increases as the size of the population decreases. Reproduction is less successful at low population densities, e.g. caused by the difficulty in finding mates, and this too is called depensation. Compares with compensatory mortality where the mortality rate decreases as the population size decreases.
Disease:	A condition of the body, or some part or organ of the body, in which its functions are disturbed or deranged. In fish, indicated by discoloration, mortality, behavioural changes (fish do not swim, or remain near surface), poor growth, changes in the quality of the flesh.

Enhanced salmon:	Salmon assisted by humans to get increased numbers, usually by increasing survival in the freshwater life stage and sometimes for a short time in the early ocean life stage.
Enhancement:	Man-made alterations to natural habitats or application of artificial culture techniques that are intended to lead to increased abundance of juvenile salmon.
Escapement/escapes:	The number of fish escaping from a fishery. Escapement from all fisheries is the spawning escapement (i.e., the fish reaching their natal spawning ground).
Spawning escapement	= the total number of adult fish returning to a hatchery or stream to spawn.
Excess Salmon to Spawning Requirements:	A form of license granted by DFO to harvest salmon that are surplus to broodstock needs of an enhancement facility.
Evolutionarily significant unit:	A set of populations that is morphologically and genetically distinct from other similar populations, or a set of populations with a distinct evolutionary history.
Exploitation rate:	The proportion of a population at the beginning of a given time period that is caught during that time period (usually on a yearly basis). Also the ratio of fish caught to total mortality (= F/Z when fishing and natural mortality take place concurrently (Ricker, 1975)). Also called rate of exploitation. Abbreviated as E.
Fecundity:	The number of eggs per female.
Fed fry:	Fry that are fed for a limited time and released before they have smolted (cf. unfed fry, which are fish that are artificially raised until their yolk sac is absorbed and the fry are ready to feed on their own).
Fish culture:	Cultivation of fish from broodstock (aka artificial production).
Fitness:	Survival and reproductive success, or, the relative ability of a genotype (an individual) in its environment to successfully contribute offspring to the next generation. In salmon, fitness is frequently equated to the number of progeny produced per spawn.
Foraging arena:	The area in which a juvenile fish feeds.
Founder Effect:	In genetic terms, the creation of a new population based on a very small number of parents. These "founders" may be a very limited portion of the genetic material in the source population. A "founder" event may have a similar effect but is caused within a population by a severe crash in population size.
Fry:	The stage from end of dependence on the yolk sac as the primary source of nutrition to dispersal from the redd.
Genotype:	1) the primary type of the type species of a genus; the specimen on which a genus-group taxon is based, no longer used in zoological nomenclature, 2) the genetic constitution of an individual, or all the individuals sharing the same genetic constitution.
Georgia Basin:	The Georgia Basin is an inland sea between Vancouver Island and mainland B.C. and the lands drained by the Fraser River and coastal rivers flowing

	into this sea from the Mainland (Coast Ranges) and Vancouver Island.
Harvest rate:	Proportion of fish from all the fish available to the fishery caught by a singly fishery. The exploitation rate is the proportion of a stock of fish caught by all fisheries combined.
Hybrid vigor:	An increase in the fitness in a population due to the masking of recessive deleterious genes due to the mating of unrelated animals, usually from different populations.
Inbreeding depression:	A loss of fitness in a population due to increasing relatedness of individuals within the population, and through the expression of deleterious recessive genes due to mating of related individuals.
Inbreeding:	The mating together of individuals that are related to each other by ancestry: increased levels of inbreeding results in a loss of genetic variation within the population.
Introgression:	Gene flow between populations that hybridize, i.e., the introduction of genes from a non-local population via the inter-mating of the two populations. The extent of gene flow depends on hybridization effects. Enhanced productivity may increase the rate of exchange (e.g. hybrid vigor), but reduced productivity over time (e.g. outbreeding depression) would reduce it.
Japanese-style hatcheries:	Hatcheries in which the eggs are incubated in gravel-filled troughs.
Juvenile salmon:	Salmon in their early life stages: fry, smolt. The period of these stages differs between salmon species.
Life stage:	For wild salmon the life stages are: *alevins* emerge from eggs and reside in the gravel, *fry* emerge from the gravel and reside in freshwater or migrate to the sea, *parr* (pre-smolt) reside and grow in freshwater, *smolts* are a transition phase from freshwater parr to seaward migrants, *adults* live at sea until migrating back to their natal streams to spawn. (Stages from fry to smolt are also known as juveniles).
Marking:	An identification system involving various methods (fin clipping, colouring, biotelemetry, radioactive markers, tattooing, branding, tagging, etc.), used for individual identification and for studies on movement, growth and other biological studies.
Mark-only fishery or, mark-selective fishery:	A fishery (often a sport fishery) in which most or all of the fish allowed to be retained are marked fish, indicating their hatchery origin.
Mass marking:	Marking all individuals in a population of fish so that individuals can be identified later in their life history. Mass marking technology utilizes chemical or thermal equipment which automatically removes adipose fins, so that coded-wire tags (CWTs) may be inserted.
Mixed stock fishery:	A fishery which harvests two or more stocks or populations together. Often such fisheries exploit the stocks present to their combined average abundance, thereby over-harvesting less productive stocks and under-harvesting more productive stocks.
Morbidity:	The prevalence and severity of impacts of disease.

Oligotrophic:	Lacking in plant nutrients and having a large amount of dissolved oxygen throughout. Used with reference to a pond or lake.
Otolith marked:	Marks on fish ear bones, by which stocked fish are differentiated from wild fish.
Outbreeding depression:	The loss of fitness in a population due to "swamping" the locally adapted genes by straying from a different population, and/or the breakdown of biochemical or physiological capabilities due to the mixing of populations with different genetic backgrounds.
Pathogen:	Agent of disease/infectious agent.
Phenotype:	The observable structural and functional properties of an organism, produced by the interaction between the genotype and the environment.
Population:	Group of individuals of one species occupying a defined area and sharing a common gene pool. For wild salmon, a localized spawning group of fish that is largely isolated from other such groups.
Production:	The total number of fish surviving to the adult life stage from enhanced or wild sources. Generally synonymous with "returns." In the enhancement context, sometimes used to mean juvenile salmon produced by a hatchery.
Productivity:	The rate of production per parent in a population. Productivity is frequently expressed as a ratio between the parent and the number of adult progeny they produce.
Recruit:	An individual fish that has moved into a certain class, such as the spawning class or fishing-size class.
Recruitment:	The new members by immigration and/or numbers of fishes born in a given year, or entering a certain class, such as the spawning class or a fishing-size class.
Recruits:	The new age group of the population entering the exploited component of the stock for the first time or young fish growing or otherwise entering that exploitable component.
Recruit-to-spawner ratio:	An estimate of the number of recruits (fish that are available for harvest in addition to those that escape the fishery to spawn) produced by the previous generation of spawners. The spawner-to-spawner ratio estimates the number of spawners (those fish that reproduced or were expected to reproduce) in one generation produced by the previous generation of spawners. A spawner-to-spawner ratio of 1.0 indicates that, on average, each spawner produced one offspring that survived to spawn; the size of such a population would remain unchanged over that generation.
Regime shift:	A pronounced and prolonged change in the characteristic atmosphere-ocean climate of a region, especially one which impacts the productivity of a fish stock.
Releases:	The juvenile fish resulting from enhancement.
Residualize:	The process in which salmon stay in the stream rather than out-migrate.
Returns:	Number of mature progeny returning from the ocean to their natal streams, i.e., catch plus escapement, the next generation of adults (prior to coming under fishing pressure, after which they are "escapes").
Run/stock:	Genetically similar group of fish having a shared source and destination

	place or time. In the wild, the group of fish that return to the same geographic area (natal watershed), or that return at the same time period.
Salmon ranching:	Raising salmon in hatcheries (at a large scale), releasing them as smolts to rear in the sea, and harvesting the returns in a terminal fishery (near where they were released).
Salmonid:	A category of fish that includes salmon, steelhead and trout.
Selective harvesting:	Harvesting that allows the unharmed release of non-target fish stocks/runs. Selection criteria may include size, stock, species and/or marks.
Smolt:	The life cycle stage of anadromous fish when they migrate to the sea to grow to adulthood.
Smoltification:	Life stage/process that is the transition from freshwater parr to seaward migrants, consisting of physiological changes that allow the fish to survive in salt water.
Spawners:	Fish which lay (and fertilize) eggs in the process of reproduction.
Stock:	See Run.
Stock-recruitment relationship:	The relationship between the level of parental biomass, e.g. spawning stock size, and subsequent recruitment level. Difficult to determine accurately – abbreviated as SRR.
Straying:	When salmon do not return to their stream or hatchery of birth.
Stress:	A response to a situation that is beyond the scope of what the animal normally encounters, although stressors may be frequent and numerous. Health may be looked at as the capacity to deal with stress without succumbing to disease.
Survival rate:	Number of fish alive after a specified time interval, divided by the initial number, usually on a yearly basis - abbreviated as S
Survival ratio:	Ratio of recruits to spawners or parental biomass in a stock-recruitment analysis. Changes in survival ratios indicate that the productivity of a stock is changing.
Terminal fishing:	Fishing of returning stocks at the mouth of the river or in the river system to which they are returning for spawning.
Wild salmon:	For the purposes of this report, salmon produced by natural spawning of parents that were spawned and reared in the natural habitat .
Year class:	The brood year (year the fish was born) or the salt-water entry year that defines a cohort of fish.

ACRONYMS

AFS	Aboriginal Fisheries Strategy (part of SEP)
APRE	Artificial Production Review and Evaluation (by NPCC)
BKD	Bacterial Kidney Disease
CCST	Central Coast
CDP	Community Development Program (part of SEP)
CEDP	Community Economic Development Program (same as CDP)
COSEWIC	Committee on Status of Endangered Wildlife in Canada
CWT	Coded Wire Tags (and see Glossary)
DFO	Department of Fisheries and Oceans, aka Fisheries & Oceans Canada
DPI	Designated Public Involvement (part of SEP)
ESA	Endangered Species Act (U.S.)
ESSR	Excess Salmon to Spawning Requirements (and see Glossary)
GSMN	Georgia Strait Mainland North
GSMS	Georgia Strait Mainland South
GSVI	Georgia Strait Vancouver Island
HEB	Habitat and Enhancement Branch (of DFO)
HGMP	Hatchery Genetic Management Plan (U.S.)
HRSEP	Habitat Restoration and Salmon Enhancement Program
HSRG	Hatchery Scientific Review Group (Washington State, U.S.)
IHN	Infectious Hematopoietic Necrosis
IMST	Independent Multidisciplinary Science Team (U.S.)
ISAB	Independent Scientific Advisory Board (of NPCC, which see)
ISBN	Individual Stock Based Management Plan
JNST	Johnstone Strait
LWFR	Lower Fraser River
MRP	Mark Recovery Program (part of SEP)
NASS	Nass Watershed
NCST	North Coast
NMFS	National Marine Fisheries Service (U.S.)
NOAA	National Oceanic and Atmospheric Administration (U.S.)
NPAFC	North Pacific Anadromous Fish Commission
NPCC	Northwest Power and Conservation Council (U.S. Columbia Basin)
NPPC	Northwest Power Planning Council (predecessor to NPCC, above)
NWVI	Northwest Vancouver Island
OPS	Operations Branch (part of SEP)
PFAR	Pacific Fisheries Adjustment and Restructuring (Program) (DFO)

PIP	Public Involvement Program (part of SEP)
PSEF	Pacific Salmon Endowment Fund
QCI	Queen Charlotte Islands
RI	Rivers Inlet
RRD	Resource Restoration Division (part of SEP)
SARA	Species at Risk Act (Canada)
SEP	Salmonid Enhancement Program
SKNA	Skeena
SRR	Stock-recruitment relationship (see also Glossary)
SWVI	Southwest Vancouver Island
TOMF	Thompson Forks (North and South Thompson)
TOMM	Thompson River Mainstem
TRANS	Trans-boundary Northern B.C.
UPFR	Upper Fraser River
WSP	Wild Salmon Policy

APPENDIX OF DATA

Figure 25: Number of Improved Natural Habitat Projects by Area and Species

JNST is Johnstone Strait; GSVI is Georgia Strait Vancouver Island; GSMN is Georgia Strait Mainland north; SWVI is South West Vancouver Island; LWFR is Lower Fraser, TOMM is Thompson Mainstem; TOMF is Thompson Forks (North and South).

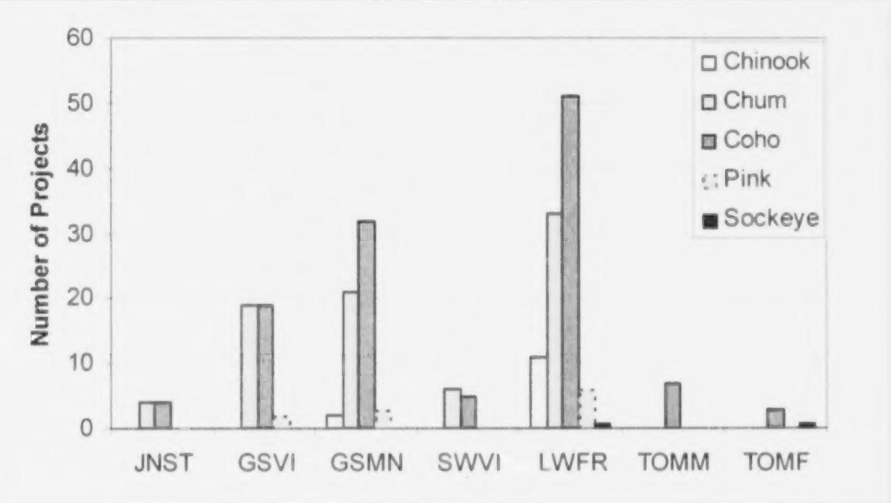

Table 11: Number of Improved Natural Habitat Projects by Area and Species

Prod. Area	**Chinook**	**Chum**	**Coho**	**Pink**
SKNA			1	
JNST		1	1	
GSMN		17	18	1
GSVI		6	6	3
LWFR	1	14	16	1
TOMM			4	
TOMF			2	
TOTAL	1	37	46	5
Ave.Releases	**225,000**	**106,000,000**	**845,000**	**700,000**
Note some projects produce more than 1 species				

Figure 26: Number of Lake Enrichment Projects and Releases by Area in 2002

Only two lakes were enriched in 2002. QCI is Queen Charlotte Islands; NCST is North Coast; SKNA is Skeena; CCST is Central Coast; RIVR is Rivers (and Smith) Inlet; JNST is Johnstone Strait; SWVI is South West Vancouver Island; UPFR is Upper Fraser.

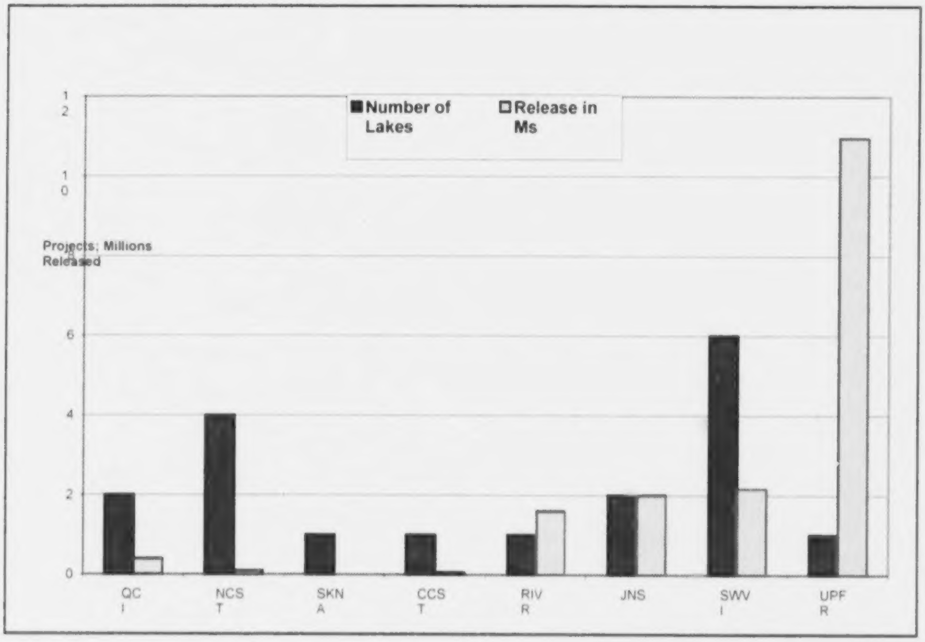

Figure 27: Size of Artificial Habitat Projects for Chum and Coho

Size is in the number of juvenile salmon (fry, fed fry and smolts) released. 'M' is millions and 'k' is thousands released, based on release targets.

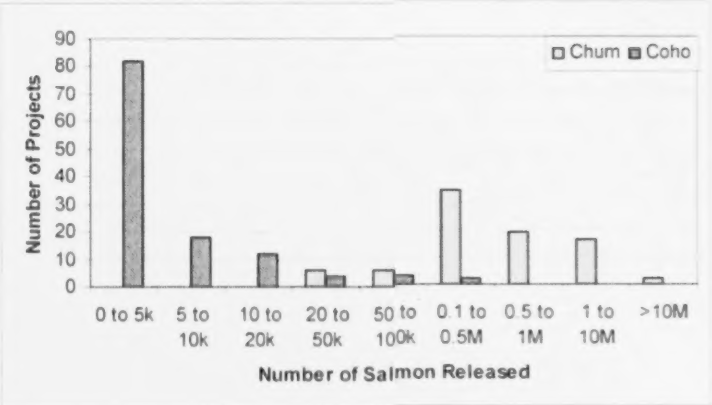

Figure 28: Size of Artificial Habitat Projects for Chinook, Pink and Sockeye

Size is in the number of juvenile salmon (fry, fed fry and smolts) released. 'M' is millions and 'k' is thousands released, based on release targets.

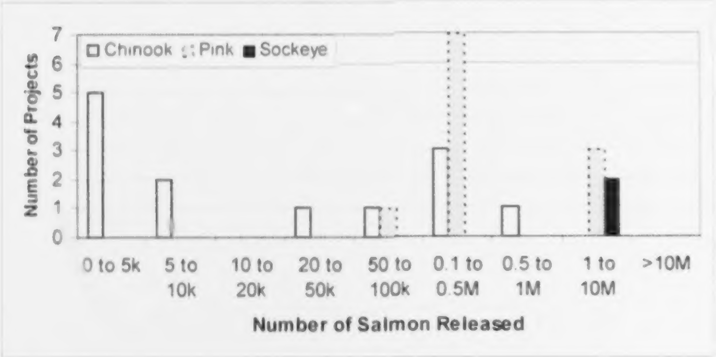

Table 12: Size of Artificial Habitat Projects

Size is in the number of juvenile salmon (fry, fed fry and smolts) released. 'M' is millions and 'k' is thousands released, based on release targets.

Releases	Chinook	Chum	Coho	Pink	Sockeye
0 to 5k	5		82		
5 to 10k	2		18		
10 to 20k	0		12		
20 to 50k	1	6	4		
50 to 100k	1	6	3	1	
0.1 to 0.5M	3	34	2	7	
0.5 to 1M	1	19			
1 to 10M	0	16		3	2
>10M	0	2			
Total	**13**	**83**	**121**	**11**	**2**

Figure 29: Projects with Artificial Habitat and Natural Spawning and Rearing by Area and Species

Spawning channels and hatchery channel combinations are included. SKNA is Skeena; GSVI is Georgia Strait Vancouver Island; LWFR is Lower Fraser; UPFR is Upper Fraser.

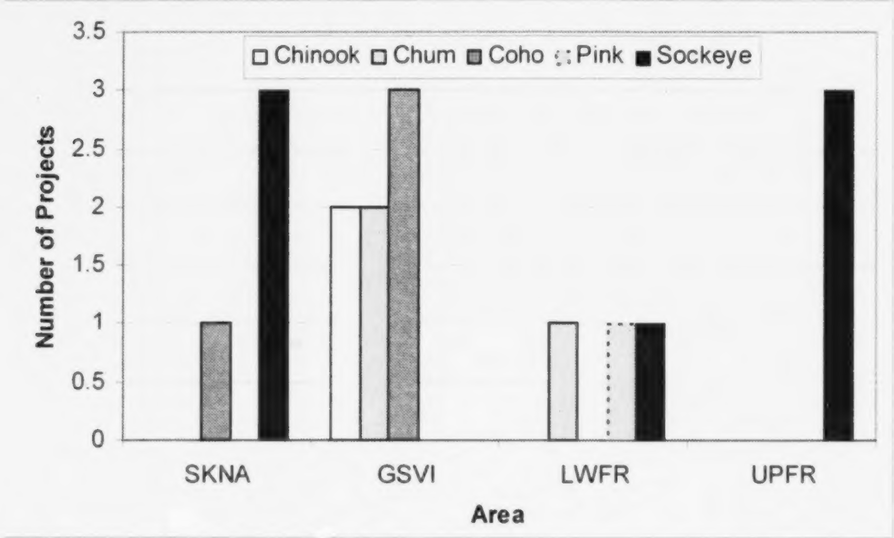

Table 13: Projects with Artificial Habitat and Natural Spawning and Rearing by Area and Species

Spawning channels and hatchery channel combinations are included. SKNA is Skeena; GSVI is Georgia Strait Vancouver Island; LWFR is Lower Fraser; UPFR is Upper Fraser. Releases are in millions and are based on targets.

Area	Chinook	Chum	Coho	Pink	Sockeye
SKNA			1		3
GSVI	2	2	3		
LWFR		1		1	1
UPFR					3
TOTAL	2	3	4	1	7
Releases(M)	**6.24**	**94.7**	**1.581**	**0.92**	**205.3**

Figure 30: Hatcheries by Area and Species (Chinook, Coho, Steelhead and Cutthroat)

YUKN is Yukon; TRANS is Transboundary Rivers in Northern BC; QCI is Queen Charlotte Islands; NASS is Nass River; SKNA is Skeena River; NCST is North Coast; CCST is Central Coast; RIVI is Rivers (and Smith) Inlet; JNST is Johnstone Strait; NWVI is North West Vancouver Island; GSVI is Georgia Strait Vancouver Island; GSMN is Georgia Strait Mainland North; GSMS is Georgia Strait Mainland South; SWVI is South West Vancouver Island; LWFR is Lower Fraser River; TOMM is Thompson mainstem; TOMF is Thompson Forks (North and South); UPFR is Upper Fraser River.

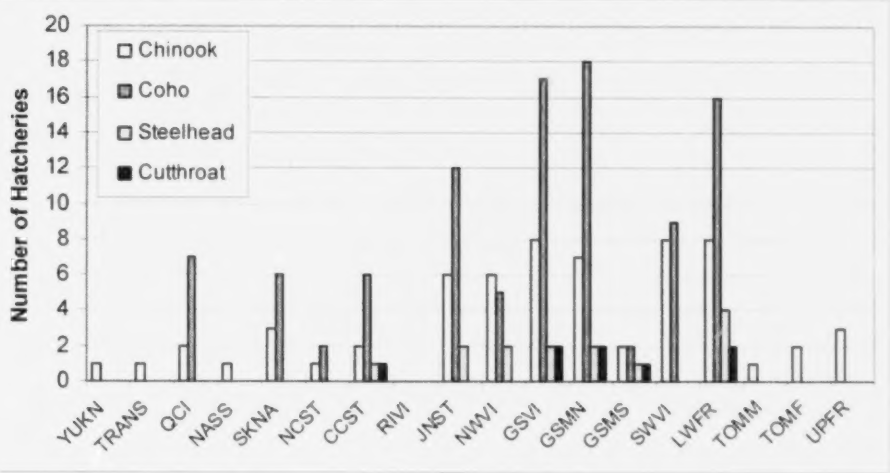

Figure 31: Hatcheries by Area and Species (Chum, Pink and Sockeye)

YUKN is Yukon; TRANS is Transboundary Rivers in Northern BC; QCI is Queen Charlotte Islands; NASS is Nass River; SKNA is Skeena River; NCST is North Coast; CCST is Central Coast; RIVI is Rivers (and Smith) Inlet; JNST is Johnstone Strait; NWVI is North West Vancouver Island; GSVI is Georgia Strait Vancouver Island; GSMN is Georgia Strait Mainland North; GSMS is Georgia Strait Mainland South; SWVI is South West Vancouver Island; LWFR is Lower Fraser River; TOMM is Thompson mainstem; TOMF is Thompson Forks (North and South); UPFR is Upper Fraser River.

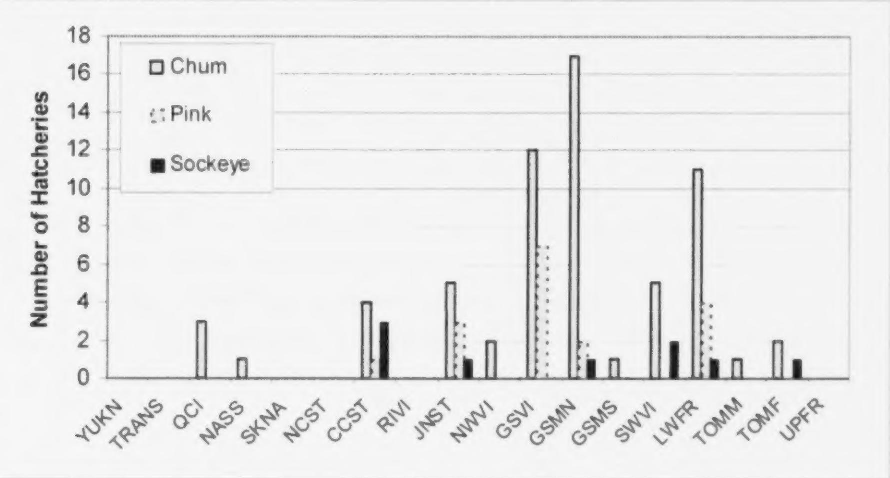

Table 14: Hatcheries by Area and Species

YUKN is Yukon; TRANS is Transboundary Rivers in Northern BC; QCI is Queen Charlotte Islands; NASS is Nass River; SKNA is Skeena River; NCST is North Coast; CCST is Central Coast; RIVI is Rivers (and Smith) Inlet; JNST is Johnstone Strait; NWVI is North West Vancouver Island; GSVI is Georgia Strait Vancouver Island; GSMN is Georgia Strait Mainland North; GSMS is Georgia Strait Mainland South; SWVI is South West Vancouver Island; LWFR is Lower Fraser River; TOMM is Thompson mainstem; TOMF is Thompson Forks (North and South); UPFR is Upper Fraser River.

Area	Chinook	Chum	Coho	Pink	Sockeye	Steelhead	Cutthroat
YUKN	1						
TRANS	1						
QCI	2	3	7				
NASS	1	1					
SKNA	3		6				
NCST	1		2				
CCST	2	4	6	1	3	1	1
RIVI							
JNST	6	5	12	3	1	2	
NWVI	6	2	5			2	
GSVI	8	12	17	7		2	2
GSMN	7	17	18	2	1	2	2
GSMS	2	1	2			1	1
SWVI	8	5	9		2		
LWFR	8	11	16	4	1	4	2
TOMM	1	1					
TOMF	2	2			1		
UPFR	3						
TOTAL	62	64	100	17	9	14	8
Releases(M)	**46.84**	**95.33**	**17.81**	**19.27**	**10.40**	**1.00**	**0.11**

Figure 32: Hatcheries by Size and Species (Chinook, Coho, Steelhead and Cutthroat)

'k' is thousands and 'm' is millions of juvenile salmon released

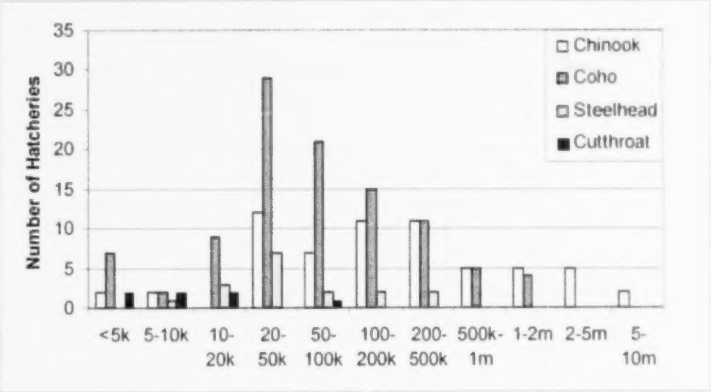

Figure 33: Hatcheries by Size and Species (Chum, Pink and Sockeye)

'k' is thousands and 'm' is millions of juvenile salmon released.

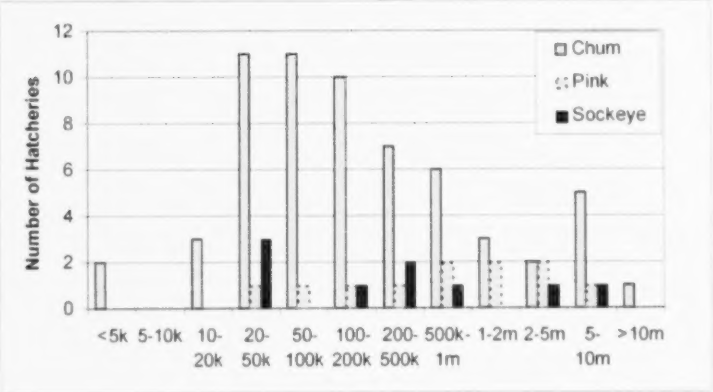

Table 15: Hatcheries by Size and Species

'k' is thousands and 'm' is millions of juvenile salmon released.

Releases	Chinook	Chum	Coho	Pink	Sockeye	Steelhead	Cutthroat
<5k	2	2	7				2
5-10k	2		2			1	2
10-20k		3	9			3	2
20-50k	12	11	29	1	3	7	
50-100k	7	11	21	1		2	1
100-200k	11	10	15	1	1	2	
200-500k	11	7	11	1	2	2	
500k-1m	5	6	5	2	1		
1-2m	5	3	4	2			
2-5m	5	2		2	1		
5-10m	2	5		1	1		
>10m		1					
Totals	62	61	103	11	9	17	7

Figure 34: Average Releases by Area by Species (Chinook, Coho, Steelhead and Cutthroat)

Lake enrichment, habitat improvement and classroom incubator releases are not included. YUKN is Yukon; TRANS is Transboundary Rivers in Northern BC; QCI is Queen Charlotte Islands; NASS is Nass River; SKNA is Skeena River; NCST is North Coast; CCST is Central Coast; RIVI is Rivers (and Smith) Inlet; JNST is Johnstone Strait; NWVI is North West Vancouver Island; GSVI is Georgia Strait Vancouver Island; GSMN is Georgia Strait Mainland North; GSMS is Georgia Strait Mainland South; SWVI is South West Vancouver Island; LWFR is Lower Fraser River; TOMM is Thompson mainstem; TOMF is Thompson Forks (North and South); UPFR is Upper Fraser River.

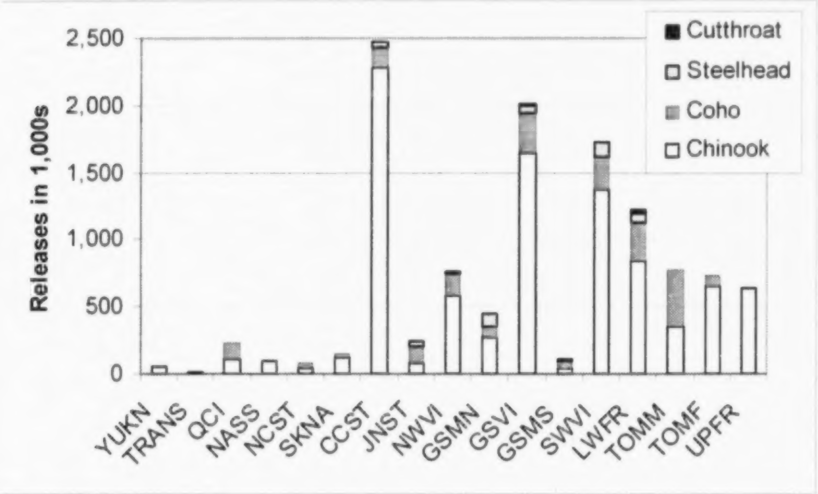

Figure 35: Average Releases (1,000s) of Juvenile Salmon by Area by Species (Chum, Pink and Sockeye)

Lake enrichment, habitat improvement and classroom incubator releases are not included. YUKN is Yukon; TRANS is Transboundary Rivers in Northern BC; QCI is Queen Charlotte Islands; NASS is Nass River; SKNA is Skeena River; NCST is North Coast; CCST is Central Coast; RIVI is Rivers (and Smith) Inlet; JNST is Johnstone Strait; NWVI is North West Vancouver Island; GSVI is Georgia Strait Vancouver Island; GSMN is Georgia Strait Mainland North; GSMS is Georgia Strait Mainland South; SWVI is South West Vancouver Island; LWFR is Lower Fraser River; TOMM is Thompson mainstem; TOMF is Thompson Forks (North and South); UPFR is Upper Fraser River.

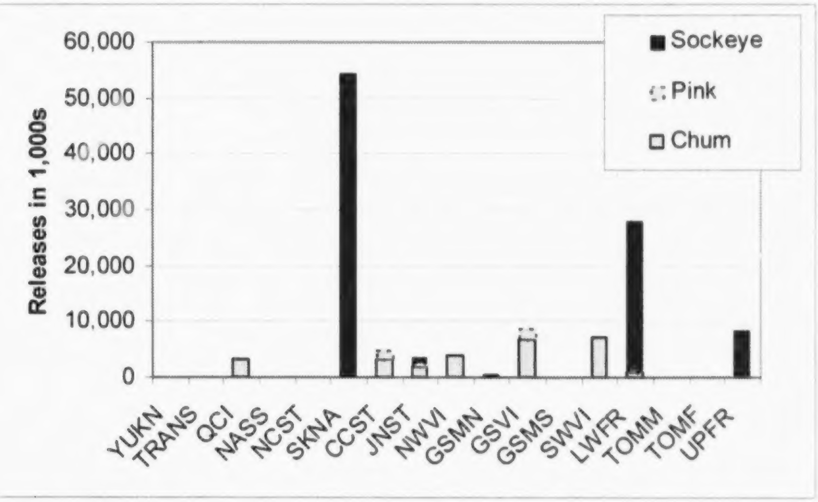

Table 16: Average Releases (1,000s) of Juvenile Salmon by Area by Species

Lake enrichment, habitat improvement and classroom incubator releases are not included. YUKN is Yukon; TRANS is Transboundary Rivers in Northern BC; QCI is Queen Charlotte Islands; NASS is Nass River; SKNA is Skeena River; NCST is North Coast; CCST is Central Coast; RIVI is Rivers (and Smith) Inlet; JNST is Johnstone Strait; NWVI is North West Vancouver Island; GSVI is Georgia Strait Vancouver Island; GSMN is Georgia Strait Mainland North; GSMS is Georgia Strait Mainland South; SWVI is South West Vancouver Island; LWFR is Lower Fraser River; TOMM is Thompson mainstem; TOMF is Thompson Forks (North and South); UPFR is Upper Fraser River.

Area	**Chinook**	**Chum**	**Coho**	**Pink**	**Sockeye**	**Steelhead**	**Cutthroat**
YUKN	56.3						
TRANS	20.3						
QCI	103.0	3,381.7	129.5				
NASS	101.3	21.6					
NCST	36.0		45.1				
SKNA	117.7		25.8		54,333.3		
CCST	2,279.0	3,231.0	156.4	1,500.0	221.7	37.1	
JNST	86.5	1,909.4	118.6	754.2	800.0	43.2	
NWVI	590.6	3,880.4	154.1			17.6	
GSMN	266.8	224.0	83.8	230.0	40.0	97.5	2.8
GSVI	1,637.5	6,961.8	311.3	1,863.9		48.3	11.5
GSMS	39.6	97.5	54.3			10.1	10.1
SWVI	1,370.5	7,165.7	244.1			117.4	
LWFR	846.0	868.6	275.3	584.3	26,650.0	70.3	35.0
TOMM	350.0		422.4				
TOMF	652.5		80.3				
UPFR	634.7				8,500.0		

APPENDIX 1: NOTE ON THE USE OF U.S. AND CANADIAN STUDIES, EXPERIENCE AND REFERENCES

This report contains information on American as well as Canadian experience and research studies. This note summarizes some of the significant points of difference and points of commonality between the two. The American experience and research, in Washington, Oregon and the Columbia River Basin, is informative in many areas, but total, blanket acceptance of it is inappropriate. Its use should be qualified by the cautions noted below. Canadians can take advantage of U.S. research (some of it even done by Canadian researchers) – but should be aware of differences that may limit its applicability in the Canadian setting.

Points of Commonality

U.S. and Canadian researchers have addressed the same subject matter in research studies. A body of hatchery management and operation principles and practices has developed in recent years which seems to be applicable on both sides of the border.

The North Pacific Ocean is the destination for many U.S. and Canadian hatchery salmon releases, as well as those of other nations. American research on climate change and regime shifts can productively supplement Canadian work.

Both American and Canadian hatchery reform efforts have found it difficult to move from concept to implementation. Both nations share the problem of institutional resistance to changes that significantly alter ways of doing hatchery business. Both are trying to achieve transparent disclosure of the details of hatchery activities, as a first step toward development of solutions, but have had limited success in doing so.

Hatcheries and enhancement programs in both nations have multiple audiences and constituencies, which have varying degrees of political influence. The issue of balance between the need to produce fish and the need to deal with identified impacts of that production is a central one in both the U.S. and Canada.

Budget concerns currently affect hatchery and enhancement operations in both nations. These take the form of cutbacks for research, assessment and monitoring. Thus, even as more is known about impacts, agencies are less able to analyze activities to measure these impacts.

In both nations, there is shared responsibility for hatchery and enhancement activity between federal, state/provincial, First Nations/Indian tribes, local and community actors.

In both nations, efforts are now underway to privatize hatcheries and enhancement facilities, to offload their costs from government to the private sector and community groups, and to develop alternate sources of funding for their maintenance and operation.

There may be value in comparing notes on alternate strategies and techniques.

Points of Difference

American hatcheries were developed primarily in the attempt to mitigate the effects of hydro dam construction on wild salmon. Canadian hatcheries were developed to supplement stocks, which had been declining for a number of reasons, some known, some unknown.

Some of the problems experienced in the U.S. were related to hatchery practices, such as transplants, that are not common in Canada. The Canadian enhancement program built on what had been learned from many preceding years of experience in the U.S., thereby avoiding a number of hatchery design and practice problems.

Recent American hatchery reform efforts – most notably those of Washington State and the NPCC in the Columbia River Basin – have been better funded and more comprehensive than Canada's. The organizational structures developed in the U.S., and procedures for adaptive management, use of Web technology for data collection and management, may be more advanced and sophisticated than ours and in some respects worthy of emulation.

Issues related to First Nations (Canada) and Indian tribes (U.S.) are different in many respects.

In the U.S., hatchery reform has been driven in large measure by the provisions of the 1973 federal Endangered Species Act (ESA). Canada's Species at Risk Act (SARA) only became effective in 2003. It is therefore too early to tell to what degree it might influence Canadian hatchery and supplementation activity. Researchers on both sides of the border have begun to compare notes on provisions of the two Acts, and on the mechanics of their implementation. (In the U.S., the present federal administration reportedly now seeks to weaken the ESA provisions that protect wild salmon.)

The Canadian SEP program had the distinction of being one of the most heavily monitored and evaluated enhancement programs in history. However, much of that monitoring and evaluation is now largely of historical interest. Funding cutbacks seem to have limited monitoring and assessment of post-SEP activities.

APPENDIX 2: EVALUATIONS OF THE SALMONID ENHANCEMENT PROGRAM

This Appendix describes some of the evaluations, consultations, studies and reports that have dealt with SEP over the years.

The analyses cover a wide range of subject matter, ranging from economic to educational to managerial to biological information. For most of the program's life, it has faced budget cuts or the threat of them, so prioritization of activities has been a fairly constant concern.

General framework for evaluation of SEP projects

SEP program reviews use a multiple account evaluation system for comparing the benefits of different operational facilities and other activities. First, program managers meet with staff to review all operations and activities for potential budget reductions, focusing on improved efficiency, savings from project reductions, and other opportunities for partial or complete funding cuts. This information is reviewed in the context of national and regional priorities.

Production projects are evaluated and ranked based on their contribution to SEP objectives. This ranking is based on performance indicators for various kinds of benefits – economic (benefit-cost ratio), employment, Aboriginal, public involvement, conservation, assessment, project efficiency and effectiveness, regional development, and sustaining fisheries.

Prior to 1995, the emphasis in project ranking was on the benefit-cost ratio. Factors such as conservation impacts, importance of assessment data, and public involvement were typically used to decide among projects with a relatively low benefit-cost rating. The overall result is: 1) projects with a high benefit-cost ratio were protected; 2) projects with moderate or low benefit-cost ratio but moderate to high conservation, assessment or public involvement value have been protected; and 3) funding for projects that did not meet these criteria has been discontinued or substantially reduced.

Evaluations, Consultations and Studies of the 1970s, 1980s and 1990s

At the beginning of the SEP program, extensive consultations were held around the province to get public input on desired program components and emphases. The transcripts and written submissions are included in Fisheries and Marine Service Canada.1977b, 1978. A second round of major meetings was held during the winter months of 1978/79 (Fisheries and Oceans Canada (DFO) 1979). Academic researchers also contributed their ideas for program design (Walters 1975).

An evaluation was conducted at the end of Phase I of the program (Levelton and Doucet 1984). Marvin Shaffer and Associates conducted an economic impact analysis of the SEP program in 1988 (Marvin Shaffer and Associates 1988). In 1988 DFO prepared an evaluation framework for the program (Fisheries and Oceans Canada 1988). This was followed in 1992 by an internal DFO evaluation assessment document (Fisheries and Oceans Canada 1992).

In a more specifically targeted 1992 study, Ray Hilborn examined DFO's ability to evaluate and learn from its experience in building and operating six artificial spawning channels as part of the B.C. SEP program. He concluded that DFO had learned well in some areas but not in others, and made recommendations to guide future management and evaluation activity. The work was described as "part of a large project looking at other SEP technologies" and also mentioned work in progress studying "learning in hatchery production for coho and in lake enrichment for sockeye

(Hilborn 1992). Hilborn and Winton published a more general article on "lessons learned" from SEP in 1993 (Hilborn and Winton 1993).

Two program evaluation reports were written in 1993 and 1994. These included the ARA Consulting Group's 1993 program review (ARA Consulting Group 1993) and the 1994 Pearse Report (Pearse 1994). The Pearse Report supported continued funding, while calling for more cost recovery, increased stakeholder participation, and better integration with harvest management. The review focused on the substantial fish production and harvest resulting from SEP projects and its contribution to salmon stock and conservation through public stewardship and education, habitat restoration and stock assessment. A 1994 UBC Fisheries Centre workshop was held to evaluate the Pearse Report (University of British Columbia Fisheries Centre 1994).

In 1996, DFO carried out an assessment of Canadian enhanced salmon production for the period 1977-1995 (Fisheries and Oceans Canada (DFO) 1996).

A 1999 report examined alternative ways of achieving cost sharing and recovery solutions which would reduce government costs and provide more equitable ways of allocating the costs and benefits of enhancement programs. The report described experience from other programs and provided ideas that may have eventually been used in the formation of the Pacific Salmon Endowment Fund in 2001 (Centre for Community Leadership 1999; Pacific Salmon Endowment Fund 2003).

Year 2000 Consultations

Consultations held in British Columbia in the summer of 2000 sought input on the future of the Salmonid Enhancement Program (Dovetail et. al. 2000). The DFO-sponsored consultation process, which also included the Wild Salmon Policy, took place between April and July 2000. It included: meetings with provincial stakeholder groups, 16 community forums/open houses throughout British Columbia, and solicitation of written submissions. Some 850 people participated through these opportunities. Following are the key messages from these consultations (Dovetail Consulting et al. 2000). Messages on which there was the highest level of agreement are in bold typeface.

SEP funding

- **DFO should find a way to restore, and even increase, the SEP budget. Cuts were rejected before and will be protested again.**
- The integrity of the consultation process is in question, given that participants are being asked about future priorities for SEP while being told that budget cuts are final and that the WSP will affect enhancement programs.

SEP priorities

- **The various activities and benefits of SEP cannot be prioritized because they are all important, they are interdependent, and priorities will differ between regions or watersheds.**
- Habitat restoration, strategic enhancement, conservation, public involvement, education and awareness raising are the most important aspects of SEP (based on an analysis of 143 response forms – a small sample).

Importance of specific activities

- Conservation is a very important part of SEP efforts to maintain stocks into the future, but it cannot make up for other threats to salmon such as poor marine survival, over-harvesting and habitat destruction.

- **Habitat restoration is very important because long-term success of enhancement depends on improved habitat. However, restoration projects must be more effective and cost efficient, and they should be evaluated to this end. Protection of remaining intact habitat is just as important as, if not more important than, restoration. The importance of restoration and its potential effectiveness varies from region to region.**

- **Education is a long-term benefit that provides a good return on investment. Evaluations must take care not to under-value this benefit. Education, awareness and public involvement are crucial to motivating the public and political support necessary to maintain salmon and their habitat, and to ensure support from future generations. SEP's education program, in particular Salmonids in the Classroom, has been highly effective and deserves continuing support by DFO.**

- Salmonids in the Classroom should place more emphasis on the natural environment and habitat.

- **SEP's public involvement is important because it brings communities together; it increases support for protecting and enhancing fish populations in B.C.; it supports education and awareness raising; and it supports volunteers who provide a resource of information and hands on support. Community Advisors are widely appreciated. Evaluation of hatcheries that are the hub of public involvement should take these benefits into account.**

- **People are passionate about volunteer stewardship with SEP. The contributions of volunteers are immense, and the effectiveness of SEP and other aspects of DFO's work depend on ongoing budgetary and staffing support for stewardship. Cutting back funding to volunteers, after all they have contributed, would be unfair. The Streamkeepers program is a fundamental underpinning of SEP.**

- Many benefits connected with SEP facilities are intangible (e.g., sense of pride from involvement in enhancement) or immeasurable (e.g., rebuilding stocks at risk). Therefore, the value of facilities should not be primarily determined by the economic returns from fish production.

- **Economic benefits from SEP facilities are especially important in remote areas, areas where unemployment is high, in coastal communities, rural communities, and small communities. In areas that depend on hatcheries for fish, people would be disproportionately affected by hatchery closures.**

- SEP should focus on benefits for wild salmon, with benefits to communities being a result of wild salmon conservation; other regional development programs should address employment and local economic well-being.

- Production for fisheries is a high priority during the current crisis in fisheries, especially in areas that depend on hatcheries. If certain hatcheries shut down, they would be sorely missed.

- Hatchery releases are highly important to the sports fishery, which is critical to the economies of many communities, and which contributes large sums of money to the provincial economy.

- Cultivation for sustaining fisheries poses risks to wild salmon, leads to an over-reliance on hatcheries, and masks factors causing declines in stocks such as over-fishing and habitat damage. Fish production should no longer be a priority of SEP. Efforts should instead turn toward restoring natural runs.

- Production for fisheries should focus on small facilities, and the enhancement of systems or specific streams experiencing critically low returns. The importance of production depends on the stream, river or watershed under consideration.

- **Strategic enhancement is a high priority for SEP facilities because human impacts on salmon need to be corrected, salmon play an ecological role, genetic diversity should be conserved, and endangered stocks will not recover on their own.**

- Salmon should be cultured only when a run is threatened with extinction and only as a temporary measure until the run is secure.

- The potential effectiveness of strategic enhancement is limited by several factors, including: the carrying capacity of the ocean, the potential for becoming dependent on enhancement for the long term, scientific uncertainty, and lack of remediation of other limiting factors such as habitat destruction.

- SEP's contribution to other DFO programs, particularly through the collection of data, is important to improved decision-making and the implementation of successful management strategies. Volunteer effort fills gaps in the Department's otherwise insufficient monitoring and assessment work.

Implications of the WSP for SEP

- The WSP should not lead to the erosion of community-based programs and the closure of facilities.

- SEP could help in the implementation of the WSP, particularly through data collection, habitat restoration and volunteer stewardship. Other aspects of SEP should be reoriented to take into account the threats of cultivation to wild salmon. Increased use of fish marking, a focus on strategic enhancement in cultivation, and more terminal fisheries could reduce the impact of fish production on wild salmon.

Evaluating and adapting SEP

- **SEP should be adapted to favour more natural forms of enhancement over cultivation and to focus public involvement/volunteer momentum on activities such as habitat restoration or data collection rather than cultivation. Hatcheries and their staff could continue to support SEP activities by focusing less on production and providing a base for stewardship activities, acting as watershed resource centers.**

- Smaller facilities should be emphasized over larger production facilities.

- Not enough is known about the effectiveness of SEP activities, especially habitat restoration. More monitoring and evaluation is critical to the wise use of SEP resources; however, economic indicators of success should not be over-emphasized relative to factors such as ecological impacts.

- Communities should have more local control over the implementation of the WSP, the operation of SEP and the management of fisheries generally, whether through advisory committees, regional management bodies, or co-management.

User pay

- Asking fish harvesters who benefit from SEP fish production to help to pay the costs of running enhancement facilities is justified on the grounds that those who benefit from the resource should help pay for it.

- Commercial harvesters already pay heavily for fishing and most are not in a financial position to pay more.
- There are drawbacks to the user pay approach, such as the possibility that those who were required to pay more will expect an entitlement to greater benefits.
- Charges for sport fishing could be increased through changes to licensing, and ways should be found to charge more to tourists and tourism operators.
- **Any funds raised through user pay should be directed to support fisheries programs. They should not go into general revenue.**
- Those responsible for damage to habitat (e.g., farmers, developers, logging companies, etc.) should be required to pay more because they too are users of the resource.

APPENDIX 3: CHRONOLOGY OF SALMON ENHANCEMENT IN BRITISH COLUMBIA

Pre-history – 1880s – 1937: Many hatcheries in operation, supplying canning industry

1937 – Canadian hatchery programs discontinued as result of the Foerster study.

1973 – initial proposals for the B.C. Salmonid Enhancement Program (SEP)

Related development: U.S. Endangered Species Act passed, stimulating interest in conservation hatcheries

1975 - $6 million federal/provincial funding to develop SEP program proposals

1976-78 – public hearings on the proposed SEP: expression of concern about impacts

Related development: salmon prices are strong at this time: pressure for more product.

1977 – SEP five-year phase 1 funded at $150 million

1978 – SEP consultation update

1977-84 – SEP Phase 1 funding stretched to cover 7 years rather than five

Early 1980s – provincial participation in SEP lapses

1983 – SEP Phase 2 scheduled to begin

1985 – Last B.C. hatchery built

1987 – SEP Phase 2 begins

1990 – SEP budget is $38 million

Early 1990s - Related development: B.C. salmon aquaculture begins rapid expansion. Production reaches 23.8 thousand gross tonnes.

1990-1998 - Closure of DFO-run Whitehorse, Birkenhead, Clearwater, Eagle, and Quesnel hatcheries and closure of CEDP- run Chehalis, Kitsumkalum, Terrace, Oweekeno, Skidegate, Necoslie, and Kispiox hatcheries.

1993-1994 – SEP program reviews, by ARA, Pearse

1995-96 – DFO creates HEB to consolidate SEP and habitat activities

1996 – Oceans Act enacted, requiring balanced consideration of multiple ocean uses

1997 – 99 Related development: Major U.S. hatchery studies begin in WA, OR

1998 – Federal "New Direction," Pacific Fisheries Adjustment and Restructuring (PFAR) Plan - $100 million of $400 million budget is devoted to resource rebuilding.

1998 – DFO announces five-year $35 million Habitat Restoration and Salmon Enhancement Program (HRSEP), to run until 2002. Viewed as a continuation of SEP.

1998 – Pacific Salmon Endowment Fund proposed, at $100 million level to provide long-term stable funding for habitat and enhancement-related projects

1999 – SEP budget is $27 million

2000 – DFO issues Wild Salmon Policy draft, with proposed "strategic enhancement" component, holds province-wide public consultations, combined with consultation on the future of SEP. Further SEP budget cuts threatened.

2000-01 - SEP changes from a separate program to part of an integrated area management organization.

2001 – SFU conference on Future of Hatcheries; initial WA State findings released. Agreed that reforms are needed; no actions come out of the meeting, however.

2001 – Pacific Salmon Endowment Fund (PSEF) (see above, 1996) established, with endowment of $30 million (annual interest income of approx. $825,000). Seeks private partners, for additional funding, embarks on three pilot programs.

2002 – Canadian Species at Risk Act passed, in effect from 2003

2002 – HRSEP comes to an end

2002 – DFO proposes SEP cutbacks on the order of 25% overall, and 50% for operations and maintenance of some hatcheries

2002 and 2003 – PFRCC expresses concern to Minister regarding DFO cutbacks and their likely effects on salmon conservation, receives unhelpful response (2002), no response (2003).

2003 – B.C. Chamber of Commerce expresses concern re: proposed cutbacks in federal salmon hatchery funding, recommends continued stable level of funding and renewed commitment to funding enhancement and habitat programs

2003 – DFO continues Wild Salmon Policy internal reviews and preparation of draft guidance documents, including enhancement guidelines. Final products were expected in 2003, but have been deferred to at least 2004.

Related development (2002)– B.C. farmed salmon production now 50,000 gross tonnes, wholesale value $320 million.

Related development (2003) – Major U.S. hatchery reform study released by NPCC; further development of WA hatchery reform efforts, though budget problems threaten to limit ability to implement recommendations.

APPENDIX 4: PUTTING ENHANCEMENT INTO AN OVERALL LONG-TERM CONTEXT

Catch is the only long-term (over 100 years) information available about salmon abundance. It has been a fairly consistent measure of stock abundance through time. Catch is a result of the number of populations and spawners, their freshwater and ocean survival, and the harvest rate.

BC salmon catch reflects a composite of effects, including:

Catching Power: Until 1970, the number of fishing vessels was not limited. Since the start of commercial fisheries, fishing technology and the catching power of the commercial fleet have increased continuously. Fisheries management actions have usually lagged far behind the need to compensate for the increased catching power.

Mixed Stock Fisheries: The early commercial salmon fisheries were mainly using nets in rivers and inshore areas where they harvested a limited mix of stocks. Through time all fisheries tended to move out to meet the returning fish. As they moved out, fisheries intercepted a much broader mix of stocks. The troll fishery moved offshore and grew in response to good catches, few limits, and the Canadian government's encouragement to put pressure on the US for a favorable Pacific Salmon Treaty. The aggregate effect of mixed stock fisheries resulted in fishing mortalities that often exceeded sustainable levels for many wild stocks.

Freshwater Habitat: Over the last 100 plus years, continuing development in BC has significantly impacted the salmon's freshwater habitat and their access to it. Early in the 20th century many of the habitat impacts were very large, including: blockages by dams and landslides; and habitat loss from water use, the search for gold, and forest harvesting and agricultural practices.

Number of Populations Contributing: The documented number of populations contributing to production has decreased since the 1950s (PFRCC, 2002). From anecdotal information about the nature of early commercial fisheries practices, it is likely that the number of contributing populations decreased significantly before that period. The study by Slaney et al (1996) gives an indication of the number of populations that no longer exist, have decreased to low abundance or are unknown. Reduction of populations is related to fishing and habitat impacts.

Ocean Productivity: Recently, cyclic changes in the productivity of the North Pacific Ocean have been documented. The changes between these 20 plus year periods or regimes of high and low productivity occur rapidly in a regime shift. Superimposed on these cycles have been short-term El Nino events that are generally unproductive for salmon.

Enhancement: Enhancement, of mainly sockeye, early in the 20th century was discontinued in the 1930s because its effectiveness couldn't be proven. In the 1960s, new feeds and enhancement approaches resulted in marked increases in adult chinook and coho returns to US hatcheries. In Canada, spawning channels and hatcheries were pilot tested. Building on that experience, in 1977 the major Salmonid Enhancement Program (SEP) was started. Enhancement was intended to increase the abundance of stocks and catch.

Representative Information: To assess the relative impacts of these various factors on salmon catch requires continuing representative information on each issue. This information has tended to be very spotty for everything except enhancement. Clearly, lack of regular monitoring makes it impossible to determine the actual impacting factors and assess their impacts.

Sockeye

The majority of sockeye production in BC comes from the Fraser River. The Skeena, Rivers Inlet, Nass and other stocks are considerably less abundant.

Appendix 4–Figure 1: BC Historic Sockeye Catch

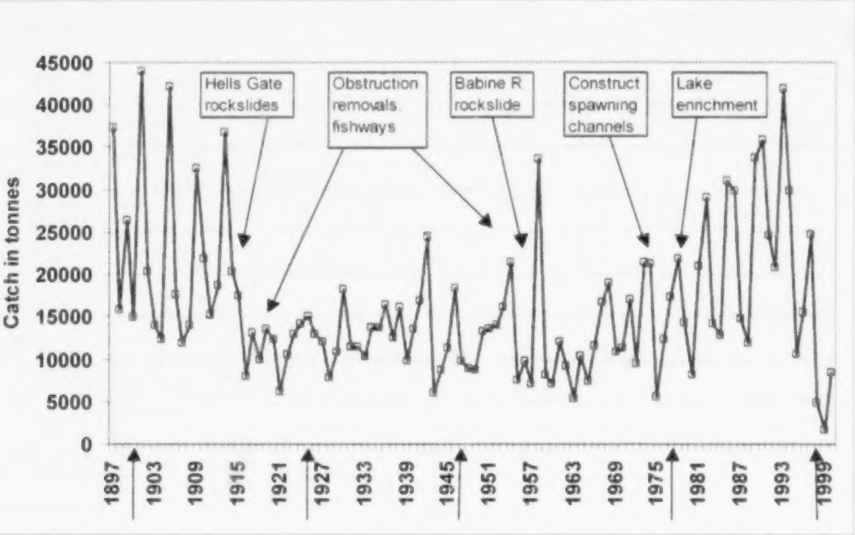

Figure 1 shows the sockeye catch from 1897 to 2000. The bottom arrows indicate ocean regime shifts. The high sockeye catches early in the commercial fishery showed a strong four-year cycle associated primarily with Fraser River stocks. The 1913 and 1914 rock slides at Hells Gate and other locations in the Fraser canyon blocked the river to salmon migration and resulted in collapse of Fraser returns that decreased the BC annual catch from an average of 23,000 tonnes to about 12,500 tonnes. Stocks decreased to very low abundance.

A number of the obstructions were subsequently reduced to alleviate fish passage at some water levels. In 1945-46 the first fishways were constructed in the Fraser canyon area to help fish past the obstructions. Over the next 20 years, a number of other fishways were constructed and obstructions alleviated to provide passage at various water levels and in other areas of the canyon. With this improved passage, Fraser sockeye populations started rebuilding.

In 1951, there was a rockslide on the Babine River that prevented most sockeye from getting upstream to spawn. It took until the winter of 1952/3 before the obstruction was removed. The 1951 and 1952 brood years were heavily impacted. In the following cycle years, special fisheries restrictions were put in place to limit catch in order to rebuild the populations. The impacts of the slide and management actions contributed to the decreased BC catch in the late 1950s and early 1960s.

In the 1960s the first sockeye spawning channels were built on the Fraser and Skeena systems. The combination of improved fish passage and increased channel production started the period of increasing production from the mid 1960s to the mid 1990s.

Figure 2 shows the total BC sockeye catch in pieces and the estimated[1] total number of adult sockeye (not just catch) resulting from enhancements such as spawning channels, hatcheries, and lake enrichment[2]. The enhanced production coincides with the increased catch. However, it is clear that all of the increased catch cannot be attributed to such enhancements. The enhancement graph doesn't include any estimate of increased production from the natural rebuilding facilitated from fishways and removal of obstructions. This rebuilding has resulted in major increases of Fraser catch.

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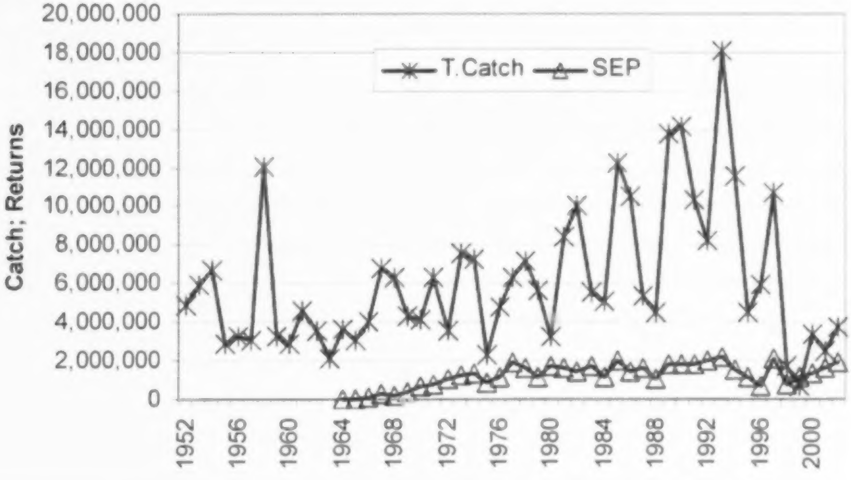
[1] Estimated using SEP biostandard average survivals for sockeye

The collapse of catch since the mid 1990s is attributed to reduced ocean survivals that affected many sockeye stocks. Also, in some years in the Fraser system, high water levels blocked upstream migration and high water temperatures stressed the fish and promoted the spread of disease. Decreased survivals and production were a result. Increased sockeye survivals and returns since 2000 are thought to reflect more favorable ocean conditions.

Appendix 4–Figure 2: Salmon Catch and Total Adult Returns to Enhancements



There has been increasing reliance on fewer sockeye populations – mainly Fraser and Skeena, secondarily Nass and Barkley Sound stocks. In the past Rivers and Smith Inlets and many smaller populations also contributed to the catch.

Appendix 4–Figure 3: Factors Affecting Sockeye Abundance By Ocean Regime Periods

SOCKEYE IMPACTS	OCEAN REGIMES				
	1899	1925	1947	1977	1998
FISHERY Fraser	Established	Managed	MSF increasing	MSF increasing	less interception
Other	Building, mainly inshore	Building, mainly inshore	Building outer coast	Increasing troll interception	less interception, selective?
CONTRIBUTING POPULATIONS	Highest	Decreasing	Decreasing	Decreasing	Increasing?
OCEAN PRODUCTIVITY	High?	Low?	High	Low	High?
FRESHWATER HABITAT Fraser Other	Hells Gate Water use	Ease Hells Gate easing	Ease Hells Gate Babine Slide	Habitat-climate impacts	Climate change Habitat impacts
ENHANCEMENT IMPACTS	Ineffective	None	None till end of period	Fraser, Babine; Lake enrichment; Multiplies fishery	Conservation Enhancement? Multiplies fishery
DOMINANT IMPACT	Hells Gate slide	Hells Gate slide	Babine Slide	Fraser natural rebuilding	All stocks rebuilding

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[2] There have been questions about the estimated number of sockeye attributable to lake enrichment. The biostandard 50% of production is used here.

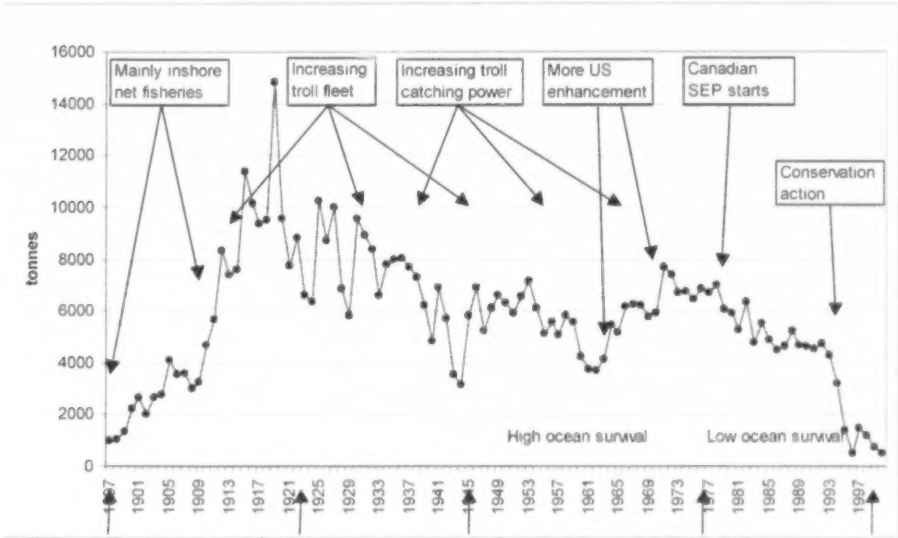
The various factors that affected the historic sockeye catch are summarized in Figure 3. MSF stands for mixed stock fishery.

At the overall level, sockeye enhancement appears to have resulted in increased catch. However, the biggest increase has probably been from obstruction removals on the Fraser and Skeena rivers. In the 1990s, catches were nearing those early in the fishery, before the Hells Gate slides.

Chinook

Figure 4 shows the historic catch of chinook in BC commercial fisheries. In the early 1900s, the catch increased rapidly with a building fishery, peaking in 1919, followed by a long period of decline. The sharp decline in the catch in the 1990s is attributed to adverse ocean conditions and to stringent conservation measures to protect at-risk stocks.

Appendix 4–Figure 4: BC Historic Chinook Catch



As Canadian enhancement of chinook didn't start until 1968, the long-term decline in chinook catch suggests some other cause of the decline. The arrows indicate ocean regime shifts in 1899, 1925, 1947/8, 1977, and 1998. (Schumacher, 1999[3], Beamish et al. 1999[4]). The 1925 to 1947 and 1977 to 1998 periods show a definite decreasing catch trend. In the 1899 to 1925 period the fishery was building. In the 1948 to 1976 period the catch was stable or increasing. This suggests that ocean productivity may be a significant factor in determining chinook production. However, it is likely that over-harvesting in conjunction with changing ocean productivity were the main factors.

Figure 5 shows the enhanced chinook total releases and marine survival (smolt to adult). Survivals include US catch of Canadian origin fish. Catches are Canadian catch of Canadian and US origin chinooks. The arrows indicate the 1977 and 1998 ocean regime shifts. The period before 1977 had very limited Canadian enhancement and high survivals[5]. The 1977 to 1998 period was when enhanced chinook releases were increasing as new projects came into operation. The 1977-98 period also had adverse ocean conditions that resulted in lower survivals than the period before 1977. The relative contribution of increased enhanced releases and adverse ocean conditions to the decreased survivals is not clear. The drop off of releases in the 1990s is related to adjusting production strategies and closing some facilities.

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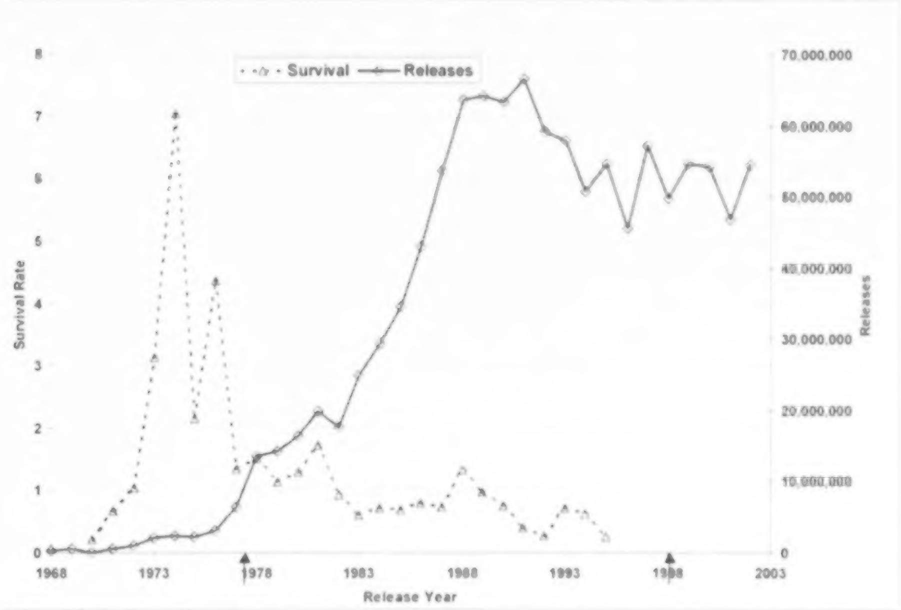
[3] Schumacher, J.D. 1999. Regime shift theory: A review of changing environmental conditions in the Bering Sea and Eastern North Pacific Ocean. Proceedings of the Fifth North Pacific Rim Fisheries Conference.

[4] Beamish, R.J., G.A. McFarlane, J.R. King. 1999. Fisheries Climatology: understanding decadal scale processes that naturally regulate British Columbia fish populations. In Fisheries Oceanography: A Science for the New Millennium. T. Parsons and P. Harrison [eds.]

Appendix 4–Figure 5: Enhancement Chinook Releases And Release to Adult Survival



There were more than 50 million juvenile chinooks released annually from 1987 onward. From 1989 to 1993, the overall catch had stopped decreasing before it collapsed in the mid 1990s. The collapse has been attributed to adverse ocean conditions and stringent conservation measures.

This is a complex assessment issue as early in the fishery, much of the chinook catch was in inshore areas and was likely of BC origin. Later, as the troll fishery increased and moved offshore, much of the catch would have been of US origin stocks. Also, growing troll and sport fisheries were taking increasing amounts of Canadian origin chinook. Much of the large US enhanced production of chinook started in the 1960s. Many of those US chinooks migrate north through Canadian waters where they contribute to Canadian catch. The increased catch helped to stimulate increased investment in the BC troll fleet and resulted in increased mixed stock fishery and excessive harvest rate problems. These pressures were later added to by Canadian chinook enhancement.

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[5] The low survivals in 1970-2 are thought to be related to enhancement startup

Appendix 4–Figure 6: Chinook Percent Enhanced by Major Fisheries

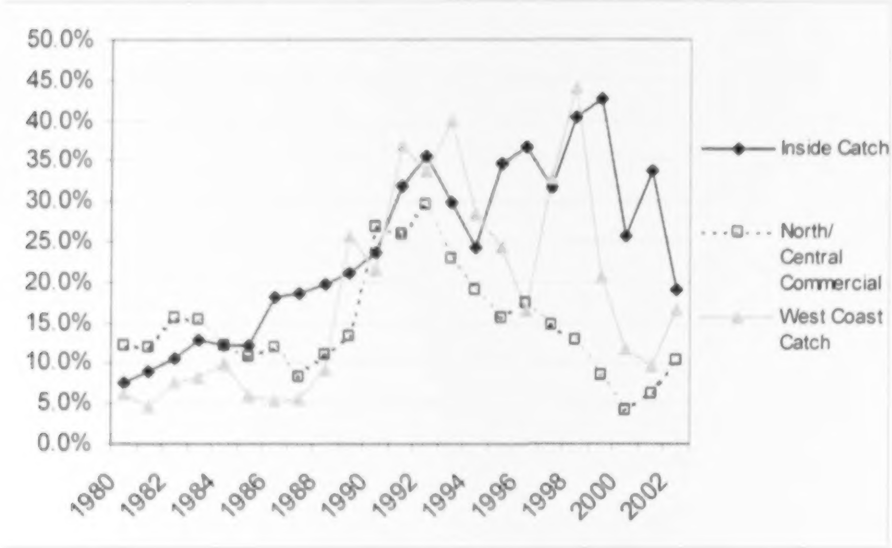


Figure 6 presents the percent of the catch that is enhanced by major fishery. Since the mid-1980s the enhanced chinook production has become a highly significant part of the overall chinook catch in BC. This is of great concern because the overall catch of chinook has continued to decrease, probably as a result of decreasing wild chinook production.

The various factors that affected the historic chinook catch (Figure 4) are summarized in Figure 7. The dominant factor in each ocean regime period is highlighted. The dominant factors are different than those for sockeye.

Appendix 4–Figure 7: Factors Affecting Chinook Abundance By Ocean Regime Periods

CHINOOK IMPACTS	OCEAN REGIMES				
	1899	1925	1947	1977	1998
FISHERY Harvest Rate	Building	Building	Building	Building	Can-US limits
Mixed Stock Fishery	Local net fishery	Net & troll mixed	High Troll interception	Very high troll interception	Reduced troll, increasing sport
CONTRIBUTING POPULATIONS	Highest	Decreasing	Decreasing	Decreasing	Increasing?
OCEAN PRODUCTIVITY	High?	Low?	High (Fig. 4)	Low (Fig. 4)	High?
FRESHWATER HABITAT	Fraser access down	Fraser access easing	Increasing water use competition	More water use, climate change	Climate change
ENHANCEMENT IMPACTS	None	None	US enhancement multiplies fishery impacts	Can. & US SEP multiplies fishery impacts	Conservation Enhancement?
DOMINANT IMPACT	Fishery	Fishery	1. Fishery 2. Enhancement	1. Fishery 2. Enhancement	?

Chinook catch has been decreasing for almost 90 years. Clearly, there are factors other than enhancement at play in the long-term decrease. Enhancement has contributed to the catch, but hasn't resulted in an obvious or apparent persistent increase in total chinook catch. Enhanced production may be aggravating fishery management and ocean capacity factors. More information is required to understand these issues. The 1998 regime shift may present an opportunity to answer some of these questions. If ocean survivals return to those in the 1947 to 1977 period, both wild and enhanced production should rebound. Also, rearing capacity would likely no longer be limiting. Then, the question is what percent enhanced chinook is desirable and from what types of enhancement.

Coho

Appendix 4–Figure 8: BC Historic Coho Catch

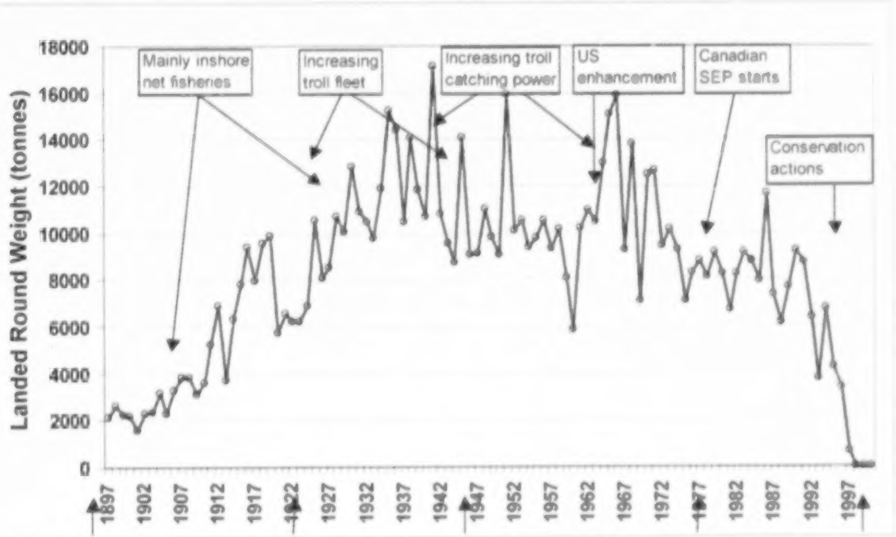
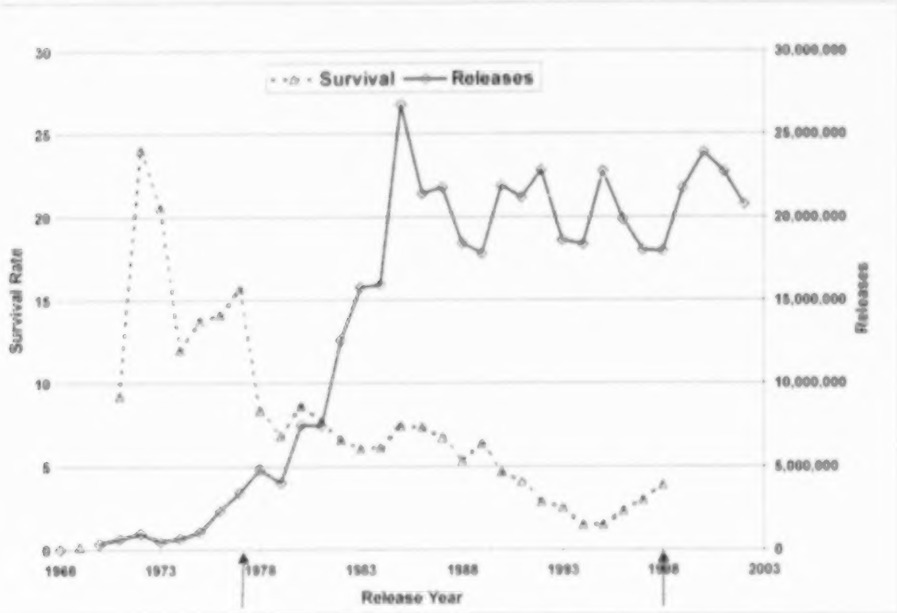


Figure 8 shows the catch of coho from 1907 to 2000. Coho catch increased until the 1930s, decreased until the 1960s when it increased, likely from US enhancement. Since then catch has declined. The increasing catch before the 1930s was primarily related to increasing fishing pressure. The fishing pressure continued to increase through to the 1990s.

The arrows indicate the 1899, 1925, 1947, 1977, and 1998 ocean regime shifts. Unlike for chinook, coho catch is still building in the 1925 to 1947 period. The 1947 to 1977 period was relatively stable until mid-1960s – about the time of increasing US hatchery production. The catch in the 1970s and 1980s was also relatively stable but at a lower level that in the previous regime. There was the same sharp decrease as in other species in the 1990s that was associated with adverse ocean conditions and conservation actions. As for chinook, the long-term decrease in catch is both a concern and an indication of causal factors other than just enhancement.

Figure 9 shows a sharp increase in enhancement releases and a sharp decline in survival rates in the 1977 to 1998 ocean regime, as for chinook. The sharp decrease in survival occurred at the time of the ocean regime shift, and before there were significant enhancement releases. The decrease in survival in the 1977 to 1998 period continued even after the enhanced production stopped increasing in the mid-1980s.

Appendix 4–Figure 9: Releases of enhanced coho and release to adult survival



Appendix 4–Figure 10: Percent Enhanced Coho by Major Fisheries

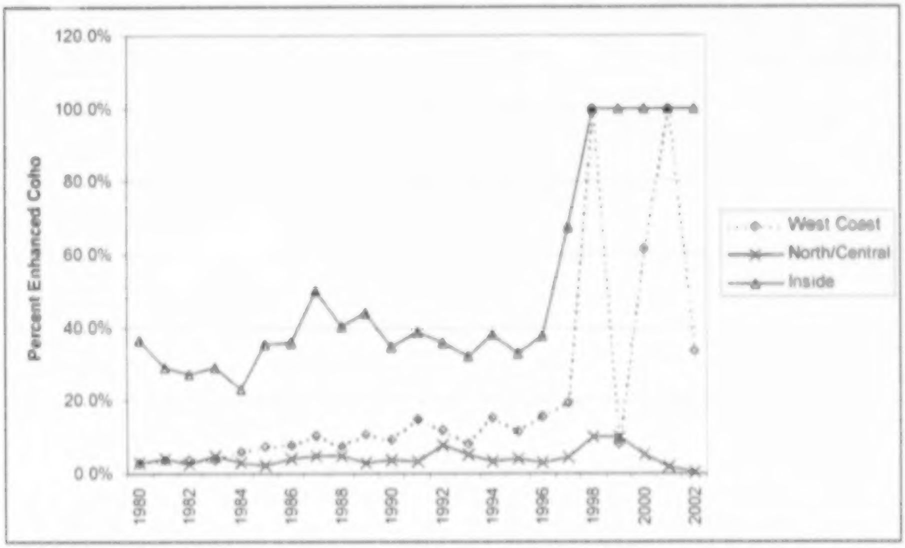


Figure 10 shows the percent enhanced coho in major fisheries from 1952 to 2002. Although enhancement was contributing 40% to 50% of coho catch in the inside fisheries and less amounts in other fisheries, the overall catch had not increased from that in the period before enhancement. The sudden changes in percent of enhanced coho after 1997 are a result of management actions to conserve wild coho, including coho non-retention and marked only retention limitations. If successful, such management actions would increase wild coho escapement and decrease enhancement surplus escapements.

Appendix 4–Figure 11: Factors Affecting Coho Abundance By Ocean Regime Periods

COHO IMPACTS	OCEAN REGIMES				
	1899	1925	1947	1977	1998
FISHERY Harvest Rate	Building	Building	Building	Building	Can-US limits
Mixed Stock Fishery	Local net fishery	Net & troll mixed	High troll interception	Very high troll sport interception	Reduced troll, increasing sport
CONTRIBUTING POPULATIONS	Highest	Decreasing	Decreasing	Decreasing	Increasing?
OCEAN PRODUCTIVITY	High?	Low?	High (Fig. 4)	Low (Fig. 4)	High?
FRESHWATER HABITAT		Less habitat in developed areas	Increasing water use competition	More water use, climate change	Climate change
ENHANCEMENT IMPACTS	None	None	US enhancement multiplies fishery impacts	Can. & US SEP multiplies fishery impacts	Conservation Enhancement?
DOMINANT IMPACT	Fishery	Fishery	1. Fishery 2. Enhancement	1. Fishery 2. Enhancement	?

The various factors that affected the historic coho catch (Figure 8) are summarized in Figure 11. The dominant factor in each ocean regime period is highlighted. The dominant factors the same as those for chinook.

It is likely that the growth and nature of coho fisheries has been the dominant cause of the long-term decrease in catch. Some actions have been taken to address over-harvesting. Rather than increasing overall catch, enhanced production has likely contributed to the decline by aggravating mixed stock fisheries over-harvest of less productive wild stocks. Under the recent decreased ocean productivity conditions, the large enhancement releases have apparently exceeded the coho carrying capacity of the Georgia Strait.

Chum

Appendix 4–Figure 12: BC Historic Chum Salmon Catch

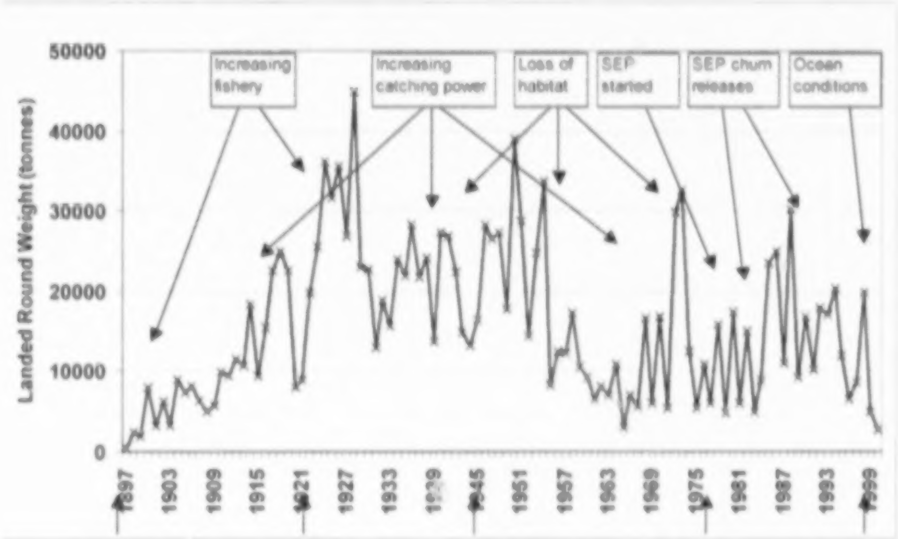


Figure 12 shows the catch of chum salmon from 1897 to 2000. The arrows indicate ocean regime shifts. Catch peaked in 1928 and then declined in stanzas until the late 1980s to the early 1990s when enhanced production peaked.

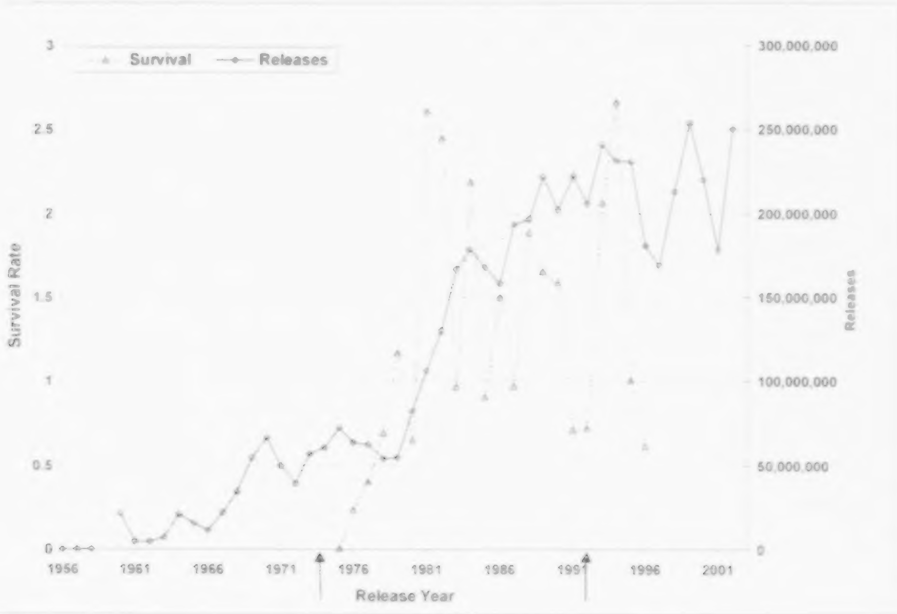
The timing of the decline in chum harvest coincides with known over-harvesting (excessive fleet and poaching) and loss of habitat. For example, the seine fleet increased from 92 vessels with an average length of 11.5m, 5 hp engines, and hand hauled nets in 1912, to 445 vessels in 1926, 14m to 24m length, 45 to 110 hp engines. By 1926 the vessels had power winches and rollers to handle deeper and longer nets and to make more sets per day (Newell, 1993). This period of rapid growth in catching power could have resulted in decreased spawners and catch in the 1930s. During the depression, prices were down and many canneries closed. Also, the 1930s were in a different ocean regime.

The pattern of decreased production differs between the ocean regimes. However, the lowest period of chum production coincides with the 1947 to 1977 ocean regime in which chinook and coho survival and ocean productivity were high.

Figure 13 shows the steady increase in enhancement chum releases from the 1960s through the mid-1980s. From the mid 1980s to the present the average releases have been about 213 million juvenile chums.

There is not enough information about chum survival before the1977 ocean regime shift to know whether survival rates were higher in the later period, as occurred for chinook and coho. Chum survival was variable but consistent from the 1970s through the 1990s, unlike chinook and coho survivals that decreased through the period. Survival factors for chums are different than for chinook and coho because chinook and coho tend to occupy coastal areas while chums occupy offshore areas and eat different foods.

Appendix 4–Figure 13: Enhancement Chum Releases And Release to Adult Survival



Appendix 4–Figure 14: Percent Enhanced Chum by Major Commercial Fisheries

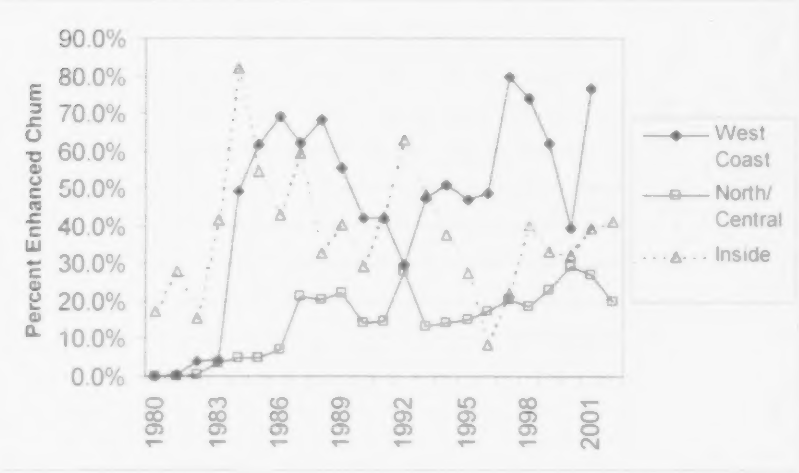


Figure 14 shows the percent enhanced chum salmon in three major commercial fisheries. The percent enhanced is related to both the amount of enhanced chum and fisheries targeted on enhanced chum. In some areas, even with targeted fisheries, some enhanced chum production goes unharvested.

At the percent of chums enhanced, the enhanced production would account for most of the increase in chum catch illustrated in the 1980s and 1990s in Figure 12.

Appendix 4–Figure 15: Factors Affecting Chum Abundance By Ocean Regime Periods

CHUM IMPACTS	OCEAN REGIMES				
	1899	1925	1947	1977	1998
FISHERY Harvest Rate	Building	Building	Building	Reduced	clockwork mgt.
Mixed Stock Fishery	Limited, mainly inshore fisheries	Limited, mainly inshore fisheries	Limited, mainly inshore fisheries	Reduced outer coast harvest	stock selective harvesting?
CONTRIBUTING POPULATIONS	Highest	Decreasing	Decreasing	Increasing	Increasing
OCEAN PRODUCTIVITY	High?	Low?	High?	Low?	High?
FRESHWATER HABITAT Fraser Other		Less habitat in developed areas	Increasing water use competition	Development impacts	Climate change? Habitat impacts?
ENHANCEMENT IMPACTS	None	None	None	Many stocks enhanced, fishery impacts	Conservation enhancement?
DOMINANT IMPACT	Fishery	Fishery	Fishery	Enhancement	?

The various factors that affected the historic chum catch (Figure 12) are summarized in Figure 15. The dominant factor in each ocean regime period is highlighted.

Unlike chinook and coho fisheries that occur on an extreme mix of stocks through most of the ocean life of the fish, chum fisheries only occur as the adults return to spawn. Chum fisheries tend to be on local stocks with much less mixed stock fishery problems and more possibility to selectively harvest enhanced returns. However, as shown in Figure 15, over-harvesting was still likely the dominant cause of declines in catch. However, coordinated management and enhancement were the likely cause of increased catch in the 1977 to 1998 period. Also, fisheries have been changed specifically to harvest enhanced chums.

Pink

Appendix 4–Figure 16: BC Historic Pink Salmon Catch

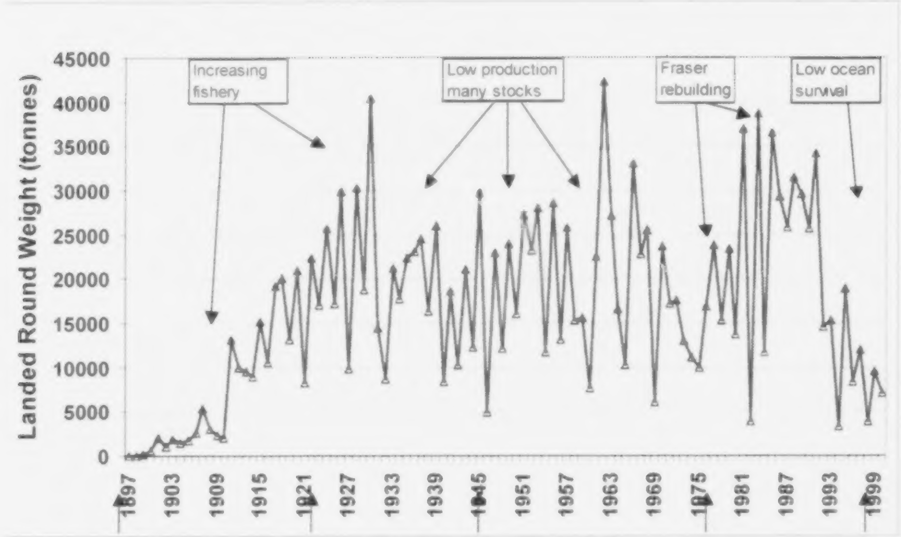


Figure 16 shows the BC pink catch from 1897 to 2000. The arrows indicate ocean regime shifts. The figure shows a number of ups and downs but on average is essentially horizontal at just below 20,000 tonnes until the 1980s when the average increased to about 30,000 tonnes. Much of that increase was in the Fraser as a result of improved fish passage in the Fraser Canyon and management changes to rebuild stocks. Like the other species, pink catch collapsed in the 1990s, probably due to poor ocean productivity, and to conservation actions for other species. It is difficult to know how much of the earlier ups and downs might have been related to changing ocean conditions.

The number of populations contributing to catch has been decreasing. For example, the PFRCC 2001-2002 Annual Report documents the reduction in the number of streams contributing to the spawning populations and hence production. For example, in the 1950s 25 streams contributed 90 percent of Georgia Strait pink spawners. By the 1990s, 90 percent was from only 11 populations. On the West Coast of Vancouver Island pink diversity decreased even more, with 80 percent of spawners coming from 15 populations in the 1950s and only to two populations in the 1990s (PFRCC, 2002).

Figure 17 shows that enhanced pink production is small compared to overall catch. Although pink salmon are relatively low cost to enhance and with a 2 year life cycle, provide a quick return on investment, there has been limited enhancement of pink salmon because of its low commercial value.

Appendix 4–Figure 17: Pink catch (number fish) and estimated enhanced adult production.

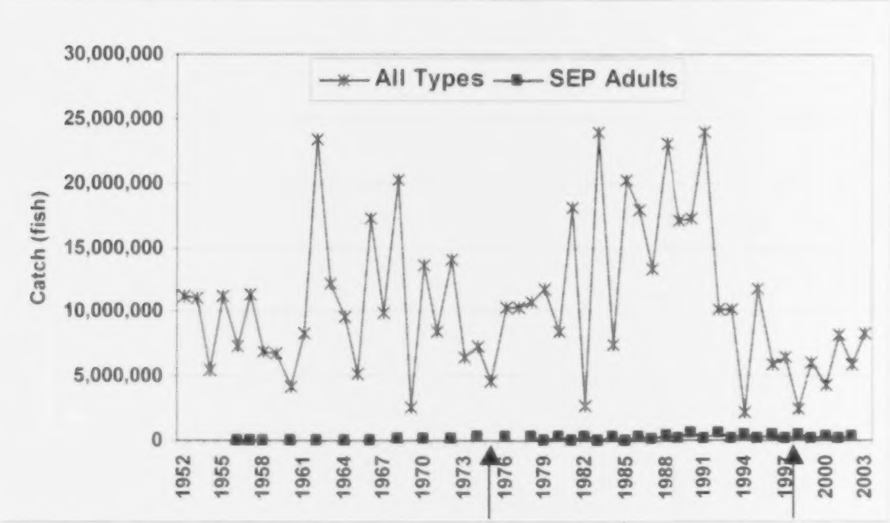


Figure 18 summarizes the various factors that have affected pink salmon catch. Probably the dominant impacts have been from the fisheries. It is not known how much changes in ocean productivity affect the long-term ups and downs of pink production. It is also not clear where pink salmon abundance will go in the current ocean regime.

Appendix 4–Figure 18: Factors Affecting Pink Abundance By Ocean Regime Periods

PINK IMPACTS	OCEAN REGIMES				
	1899	1925	1947	1977	1998
FISHERY Harvest Rate	Building	Building	Building Tr. & Sn.	Building Tr. & Sn.	
Mixed Stock Fishery	Limited, mainly inshore fisheries	Limited, mainly inshore fisheries	Building outer intercept. fisheries	Building outer intercept. fisheries	stock selective harvesting?
CONTRIBUTING POPULATIONS	Highest	Decreasing	Decreasing	Decreasing	Decreasing
OCEAN PRODUCTIVITY	High?	Low?	High?	Low?	High?
FRESHWATER Fraser HABITAT Other		Less habitat in developed areas	Increasing water use competition	Development impacts	Climate change? Habitat impacts?
ENHANCEMENT IMPACTS	None	None	None	Limited # stocks & amount enhanced, fishery impacts	Conservation enhancement?
DOMINANT IMPACT	Fishery	Fishery	Fishery	Fishery	?

Bottom Line

The next 5 to 10 years are going to be key to assessing ocean survival and enhancement impacts and contributions for all species, but especially for chums. Unless there is a serious effort to assess the array of factors affecting salmon production, efforts to assess enhancement will be inconclusive. Also, many of the existing problems will continue at some level.

If the number of populations contributing to catch continues to decrease the overall diversity and future production of salmon resources will be under increasing risk.

Actions taken to coordinate chum enhancement and management seem to have had the desired effects. It is too early to assess the effectiveness of the coho marked-only enhancement and management strategy.

Putting the overall salmon resource management initiatives into a long-term, integrated context is essential for both assessment and management. Clearly, human controlled actions should be adjusted to respond to uncontrollable natural events. Human controlled actions should be closely coordinated to complement each other.

APPENDIX 5: EXAMPLES OF INTEGRATED APPROACHES TO ENHANCEMENT

Clockwork Management: An integrated strategy implemented in B.C.

In B.C., the "clockwork management" approach to fisheries management has been applied on certain selected stocks since 1983. This approach provides a good example of an integrated system of measures to protect wild salmon.

"Formula" or "Clockwork" management lays out management options by time period for different stock abundances, timing and mixes, fleet sizes and mixes and environmental conditions in relation to key indicators so that in-season management can proceed like "clockwork" through the plan which was agreed to pre-season (Hilborn and Leudke 1987). It is a form of adaptive management, in that it permits fine-tuning and modification of the pre-season plan if new evidence during the season calls for it. In some applications it combines harvest reductions, hatchery releases and habitat restoration to achieve targets for defined "Clockwork areas" in which the technique is to be applied.

Clockwork management was first implemented in 1983 in Johnstone Strait, with the objective of rebuilding the wild component of chum stocks by controlling the overall harvest rate. A Fraser River Clockwork Plan was introduced in 1987, again with the objective of rebuilding chum stocks (DFO 1999b). In each case, incremental harvest rates are set at 10, 20, 30 or 40%, depending on run size, and adjusted in-season in response to newly received information. Before implementation of the Clockwork strategy, these two chum fisheries were set based on a fixed escapement strategy. That fixed escapement, applied to a fishery with variable recruitment, had resulted in large harvest variability.

Stave River example of Clockwork Management

The Stave River provides an example of effective use of the Clockwork management strategy. Bailey describes the components that were part of the solution to rebuilding of Stave River chum as well as the benefits that have been derived from the program:

> *"Stave River chum rebuilding was accomplished by releases of hatchery chum and reductions in exploitation rate to put the returns from this production on the spawning grounds. Extensive habitat restoration and a flow agreement [with B.C. Hydro] was undertaken so that spawning and incubation conditions were improved for production of fry from these adults. The result is a 7-fold increase in chum escapements – from 44,000 to 309,000. Hatchery releases of coho, chinook, and cutthroat trout have also increased the returns of these species and habitat restoration should substantially increase the natural production of these species. Additional benefits of this enhancement and habitat restoration include sport angling, food for other wildlife, and viewing of spawning. As the salmon life cycle is very dynamic and rivers are always changing, the Department of Fisheries and Oceans and B. C. Hydro will have to be vigilant to ensure that the conditions on the Stave River remain optimal for spawning, incubation, and rearing success." (Bailey in Brannon and McKinlay 2002).*

The Stave River chum stock has been rebuilt using an integrated combination of enhanced fry releases, reduced and controlled harvest rates, and habitat restoration. When the stock reached what appeared to be capacity, enhancement was stopped. Careful management of fisheries on this stock are continuing. Monitoring of adult returns has continued to assess the post enhancement stock trends.

Clockwork Program evaluation

During the first fourteen years of its existence, some changes were made in the Clockwork Management program, to account for increasing enhancement levels or to increase the likelihood of achieving the wild escapement goal at lower run sizes.

DFO staff members (Ryall et al. 1999) conducted an evaluation of experience with the Clockwork Management Program between the years 1983-1997. Their 1999 report concluded that the strategy had worked reasonably well in meeting escapement and harvest rate targets during that time. They felt it had successfully achieved a number of its objectives: allowing for limited commercial fishing in most years, making possible increases in wild escapement levels overall, and increasing understanding of optimal target escapement levels. However, they noted that, while catch statistics were considered to be consistently and accurately collected, "there remains significant concern over the level of escapement enumeration and accuracy of the escapement estimates upon which the Clockwork strategy …depends."

They felt there was a need to standardize data collection methods to improve escapement estimates, citing present "inconsistencies in methodologies and lack of effort directed to escapement enumeration." They noted that, since 1985, enumeration effort had declined, from 65% to less than 40% of streams being surveyed each year. Finally, they observed that, for the years under study, pre-season forecasts were "generally poor," and that their use as a Clockwork management tool was "extremely questionable." They called for a further PSARC review of programs used to estimate Fraser River escapement.

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Rivers/Smith Inlet Restoration

In the past, the Rivers and Smith Inlet area produced a long-term average catch of more than 1.2 million sockeye per year from 1900 to 1974 (Wood, 2000). Since 1975 the total catch declined until, in 1996 and 1997, when fisheries in Rivers Inlet and Smith Inlet respectively were closed (Holtby, 2000). Since 1992, the 15 Rivers and Smith Inlet total sockeye populations decreased to a fraction of historic spawning populations. The 1985 to 1994 Smith Inlet average annual return of 500,000 dropped to 5,900 in 1999 and 1,400 in 2000 (PFRCC 2001). The collapse in the 1990s was attributed to adverse ocean conditions.

The populations rapidly decreased to such low levels that enhancement was the only viable option to protect and restore the populations. Only hatchery technology could provide high enough survivals to rebuild populations in a reasonable time. To minimize any possible adverse enhancement related impacts, the plan was to minimize the years of enhancement (Holtby, 2000). The following special actions were taken to minimize risks and adverse interactions.

Fish Health: As the biggest concerns with sockeye are related to disease, particularly IHN (Infectious Hematopoetic Necrosis) and BKD (Bacterial Kidney Disease), the following special actions were taken (Hilland et al. 2001).

Separate incubation and rearing facilities for 750,000 sockeye from 9 different populations were established, in segregation to meet DFO policies, regulations and guidelines. The water supply was fish free to ensure no introduction of disease. Effluent water from incubation and rearing was filtered in an exfiltration gallery to minimize the possibility of pathogen transfer to local surface and/or groundwater. Incubation was in stacked trays, with eggs from each female in a separate tray and eggs from each stock in separate stacks of trays. The Alaskan sockeye protocol was strictly adhered to reduce potential IHN virus transmission.

Eggs and milt were obtained from fish spawning in the field and transported to the hatchery for fertilization and planting. Each fish was disinfected with iodophor solution using a new swab. Gloves and spawning knives were disinfected between fish. For each fish, eggs or milt was collected into separate disposable containers. Each female was sampled and analyzed for IHN and BKD. Fertilized eggs were rinsed in iodine solution. Gloves were discarded after each female.

Genetics: To minimize genetic risks, not more than 50 percent of spawners could be taken for brood stock (Hilland et al. 2001). To increase the expression of genetic diversity, eggs from each female were evenly divided into two separate containers; each received half of the milt from two males. Also, as a contingency plan, milt was frozen and stored in liquid nitrogen to ensure the availability of milt if ripe females were available when there were no ripe males and to provide genetic material for future years to enhance genetic diversity or for use if stock size became so low that a transplant was necessary.

Predation: Predation would be most significant from when fry emerge until they have moved to offshore areas in the lake. To minimize this, enhanced sockeye were ponded and fed for a short time to increase their release size so they wouldn't have to occupy lakeshore areas too long. Also, sockeye were helicoptered back to their natal stream in oxygenated buckets, acclimatized and released at dusk to minimize predation (Hilland et al. 2001).

Competition: with the extremely low abundances, there would be little competition for rearing space for wild or enhanced fish. There might be very limited competition between sockeye and sticklebacks in Long Lake, in Smith Inlet.

Mixed Stock Fisheries: all intercepting fisheries have been closed and will remain closed until the populations have rebuilt to an acceptable abundance (Holtby, 2000).

Relative Production: to avoid the multiplier effects of relative enhanced production, the enhancement was limited to rebuilding the populations to a safe level, over a short-time – ideally one 4 or 5 year cycle. Also, all enhanced fish were marked to allow assessing relative performance and impacts (Hilland et al. 2001).

Habitat Impacts: incubating the eggs in an offsite hatchery with established water and effluent systems minimized any adverse habitat impacts.

Other: Each step of the process was carefully monitored and recorded to learn as much as possible from the experience. There were explicit evaluation protocols for assessment of the spawning to release life stage. Later stages are being monitored opportunistically.

Results

In 2000, from 615,026 eggs collected, 528,849 fry were released – 86% survival. In 2001, from 905,867 eggs collected, 833,817 fry were released – 92% survival. In 2002, 1,012,692 eggs were collected and 912,250 fry released – 90% survival (Hilland pers. comm. 2003). In the wild, survival would likely have been about 15 percent – less with adverse environmental conditions. The enhancement increased the egg to fry survival by about six times. Also, early feeding should have increased fry to smolt survival.

This approach minimized the risks to the fish while maximizing the rebuilding rate. Only time will tell how much of a success this approach achieved. A concern is that the experiment will not be assessed because resources may not be adequate to appropriately sample for marked as compared to unmarked returns.

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